L Number	Hits	Search Text	DB	Time stamp
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8	0	5861601.pn. and standing	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2003/05/22 19:54
15	1	4985109.pn.	USPAT	2003/05/22 19:55
16	76	(microwave same (slot and (open or closed or opened))) and (156/$.ccls. or 118/$.ccls.)	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2003/05/22 20:59
23	19	(microwave same (slot with (open or closed or opened))) and (156/$.ccls. or 118/$.ccls.)	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2003/05/22 21:00
30	32	(microwave same ((slot or slit) with (open or closed or opened))) and (156/$.ccls. or 118/$.ccls.)	USPAT; US-PGPUB; EPO; JPO; DERWENT; IBM_TDB	2003/05/22 21:01

US006109208A

United States Patent [19]

Tsuchihashi et al.

[11] **Patent Number: 6,109,208**

[45] **Date of Patent: *Aug. 29, 2000**

[54] **PLASMA GENERATING APPARATUS WITH MULTIPLE MICROWAVE INTRODUCING MEANS**

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[73] Assignees: **Mitsubishi Denki Kabushiki Kaisha; Mitsubishi Electric Engineering Company Limited**, both of Tokyo, Japan

[*] Notice: This patent is subject to a terminal disclaimer.

[21] Appl. No.: **09/122,061**

[22] Filed: **Jul. 27, 1998**

[30] **Foreign Application Priority Data**

Jan. 29, 1998 [JP] Japan 10-017226

[51] **Int. Cl.**[7] **C23C 16/511**; C23C 14/00; C23C 16/00; C23F 1/02

[52] **U.S. Cl.** .... **118/723 MA**; 118/723 MW; 156/345; 204/298.38; 204/298.08

[58] **Field of Search** .... 204/298.38, 298.02, 204/298.08, 298.16; 118/723 MP, 723 MW, 723 ME, 723 MR, 723 MA; 156/345

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,265,730	5/1981	Hirose et al.	204/298.38
5,053,678	10/1991	Koike et al.	204/298.38
5,134,965	8/1992	Tokuda et al.	204/298.38
5,202,095	4/1993	Houchin et al.	204/298.38
5,387,288	2/1995	Shatas	118/723 MW
5,429,070	7/1995	Campbell et al.	204/298.38
5,874,706	2/1999	Ishii et al.	204/298.38

FOREIGN PATENT DOCUMENTS

3-191068	12/1989	Japan	118/723 MW
4-048078	2/1992	Japan .	
4-048928	2/1992	Japan .	
4-144922	5/1992	Japan	118/723 MW
6-104188	4/1994	Japan .	
6-349596	12/1994	Japan .	

Primary Examiner—Nam Nguyen
Assistant Examiner—Gregg Cantelmo
Attorney, Agent, or Firm—McDermott, Will & Emery

[57] **ABSTRACT**

A plasma generating apparatus capable of improving the uniformity of a plasma processing and coping with a larger diameter of a substrate is obtained. Microwaves are distributed and emitted from a waveguide through the branching portions of a T branch to four rod antennas. The microwaves are introduced through four dielectric tubes into a vacuum vessel. In the vacuum vessel, a multi-cusp magnetic field and an electron cyclotron resonance region are caused by permanent magnets located around the vessel and, by an interaction between a vibrational electric field of the microwaves and a magnetic field, highly uniform plasma is generated in a region where a substrate or the like is subjected to a plasma processing.

8 Claims, 10 Drawing Sheets

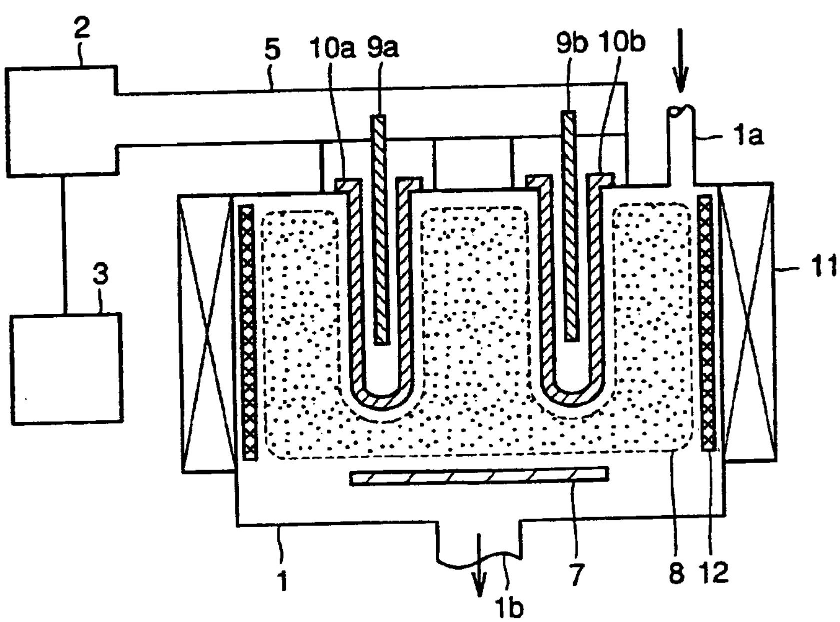
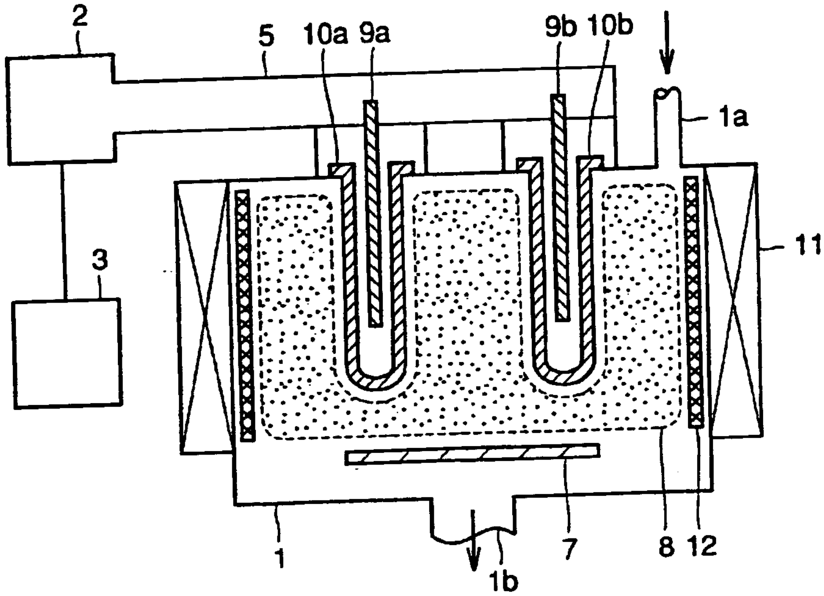


FIG. 1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9b
10b
1a
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3
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1b
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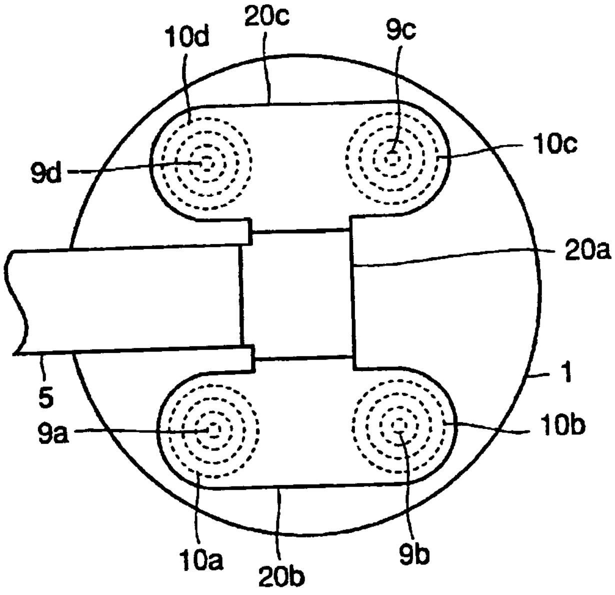
8
12

FIG. 2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9b

FIG. 3

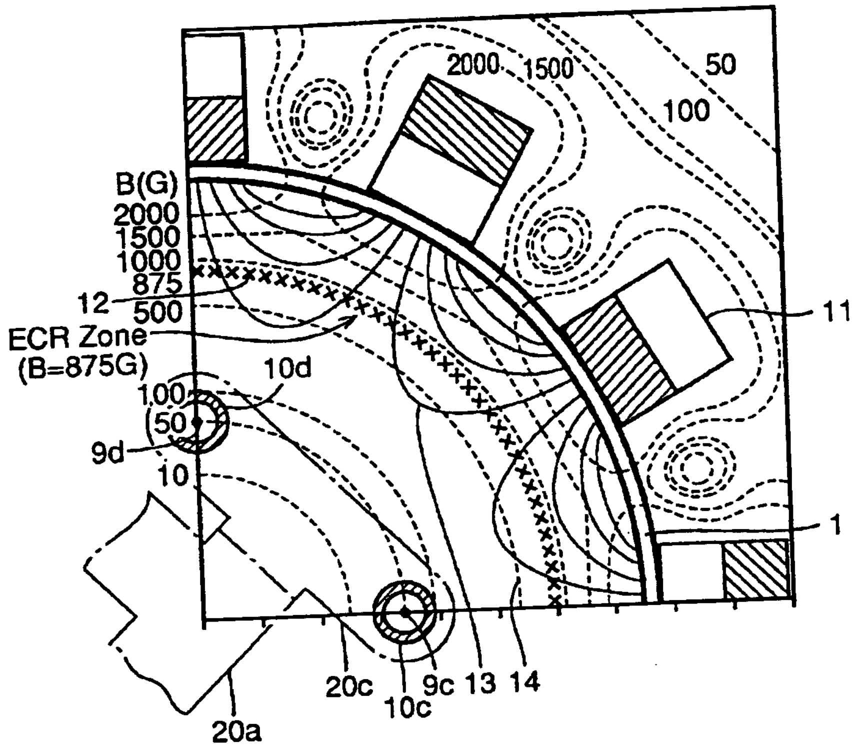

FIG. 4

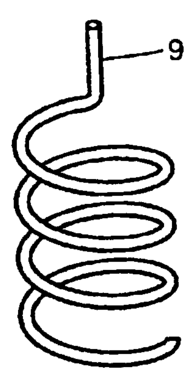

FIG. 5

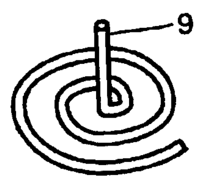

FIG. 6

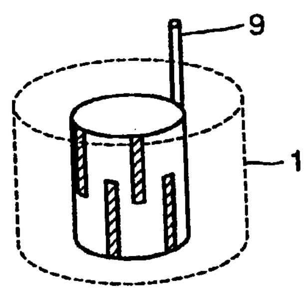

FIG. 7

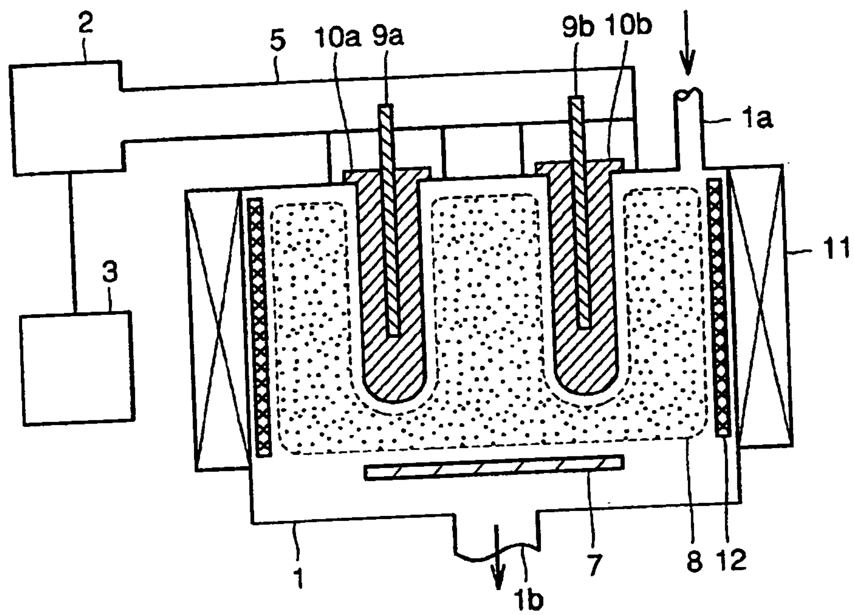

FIG. 8

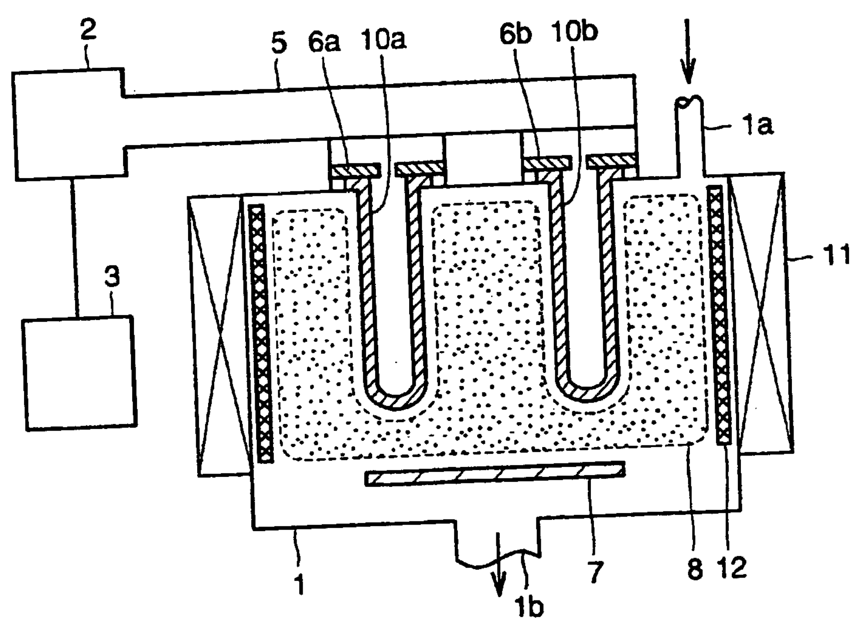

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FIG. 9

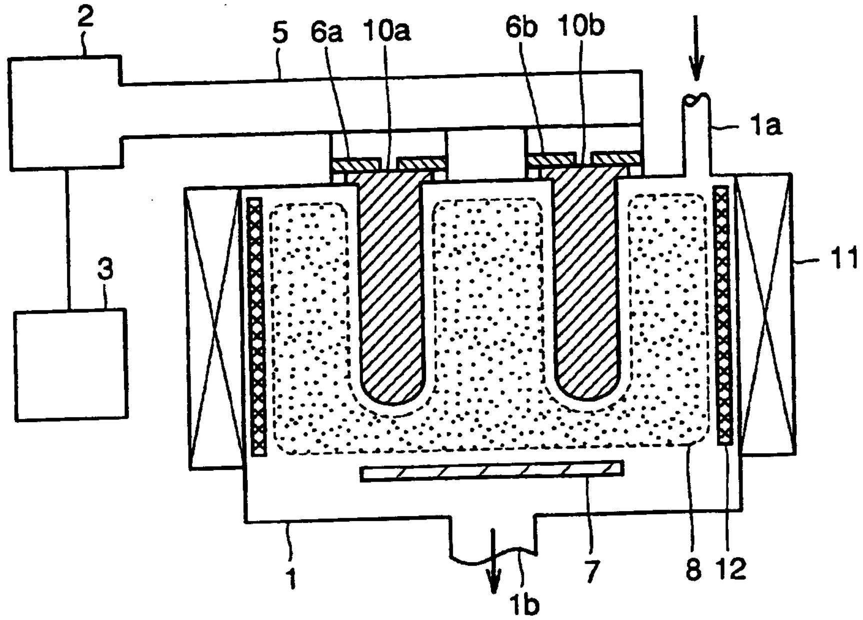

FIG. 10

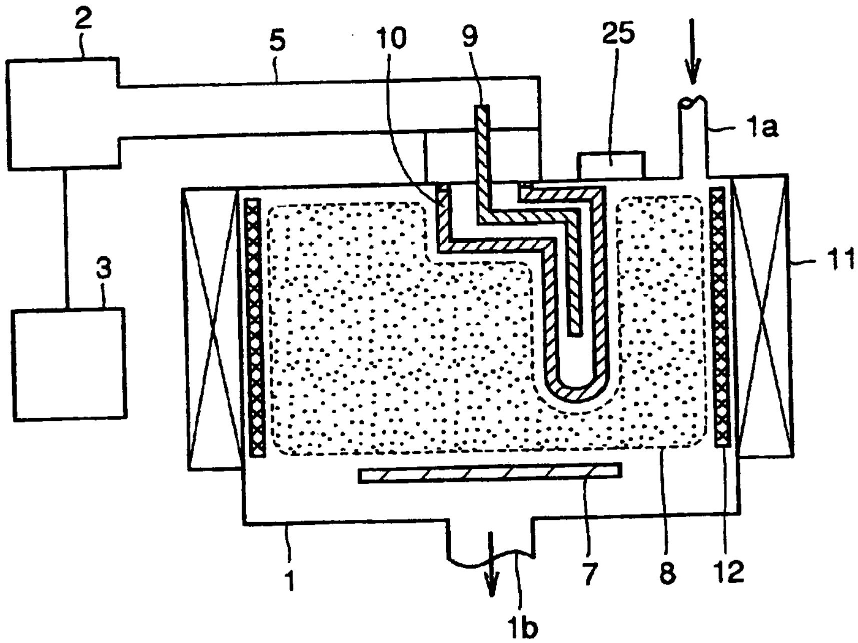

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FIG. 11

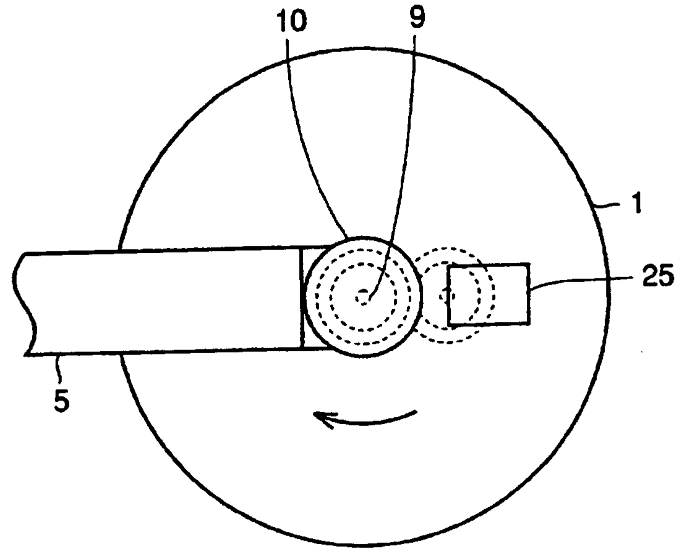

FIG. 12

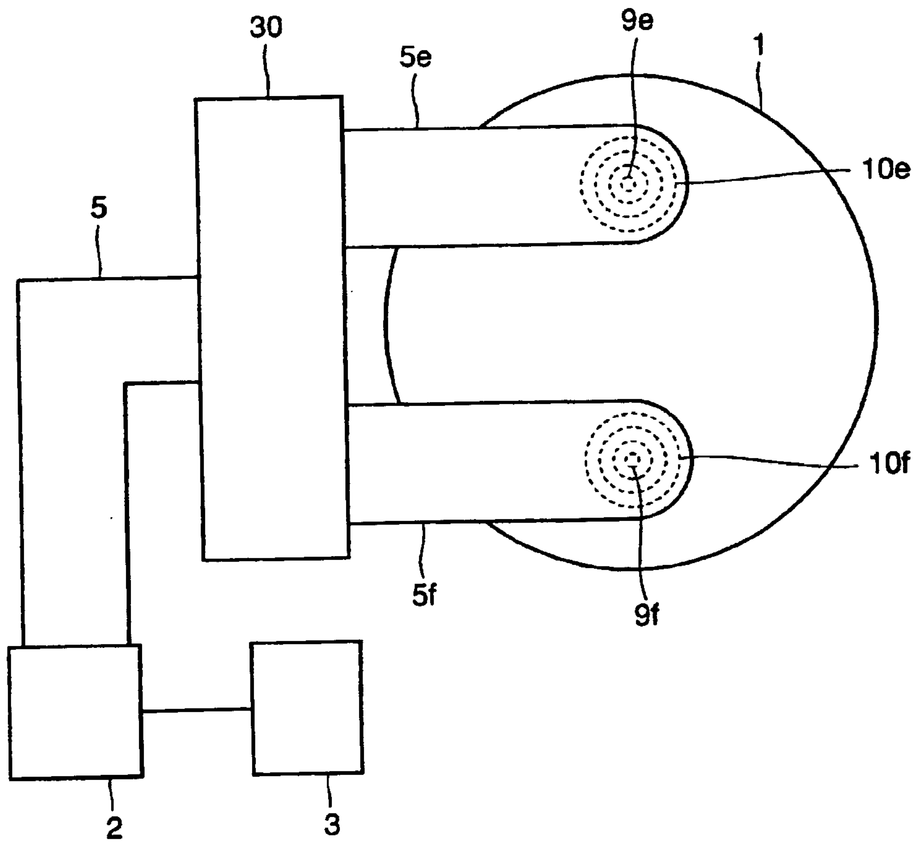

FIG. 13

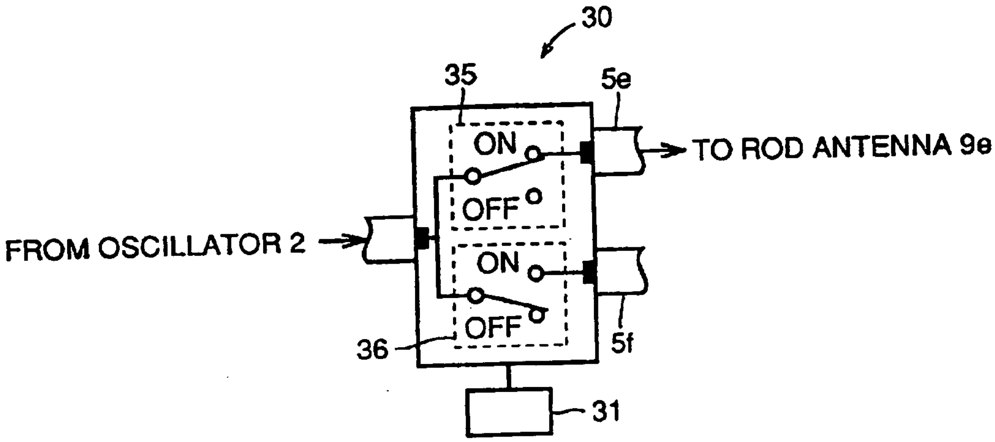

FIG. 14

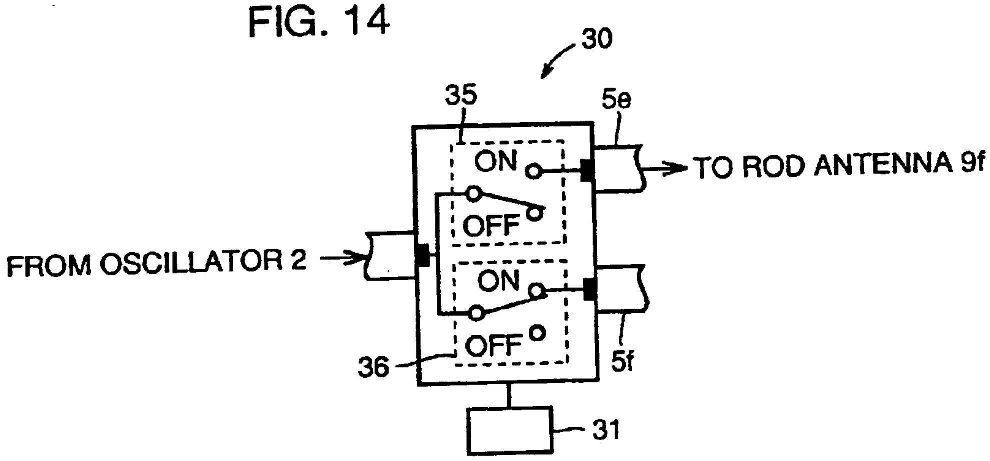

FIG. 15

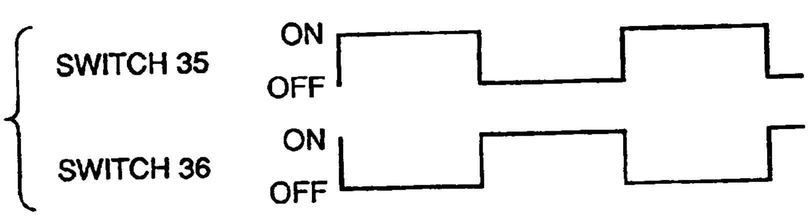

FIG. 16

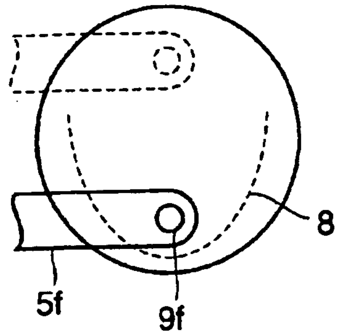

FIG. 17

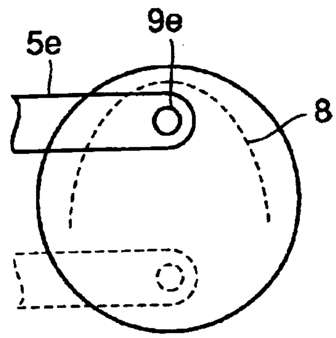

FIG. 18

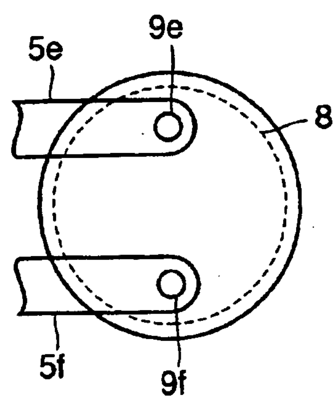

FIG. 19

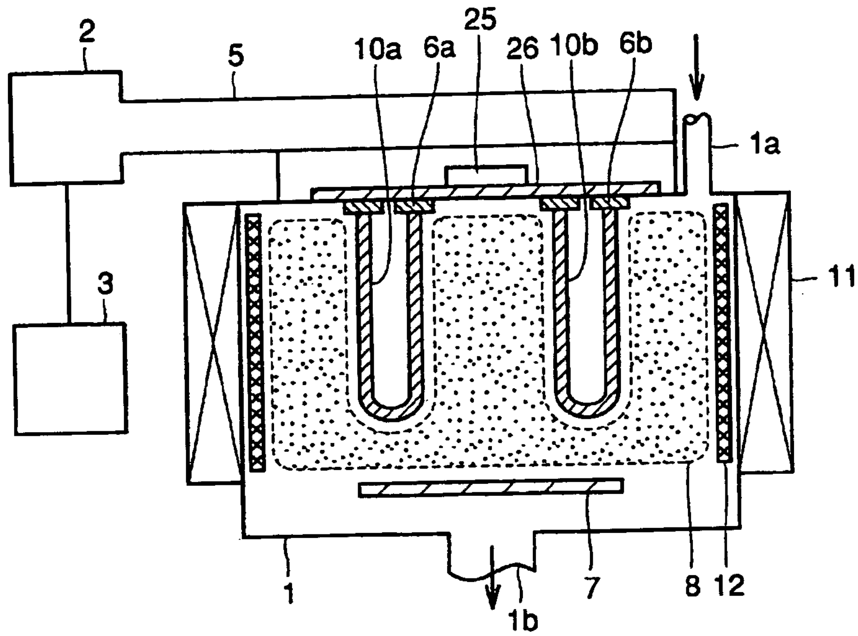

FIG. 20

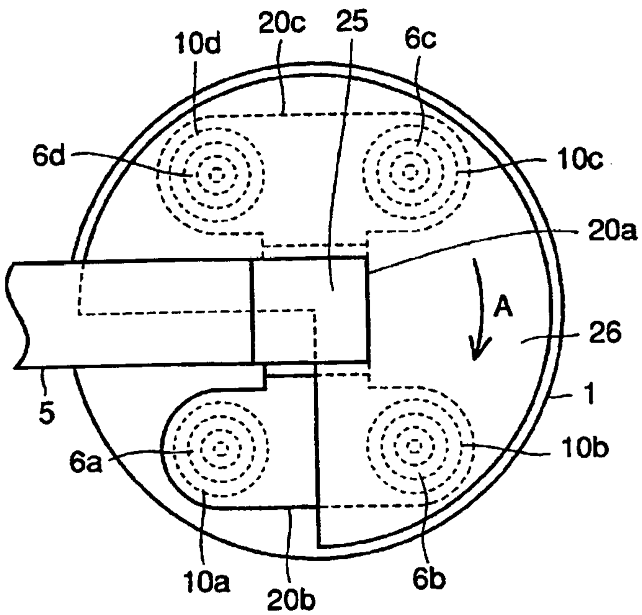

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FIG. 21 PRIOR ART

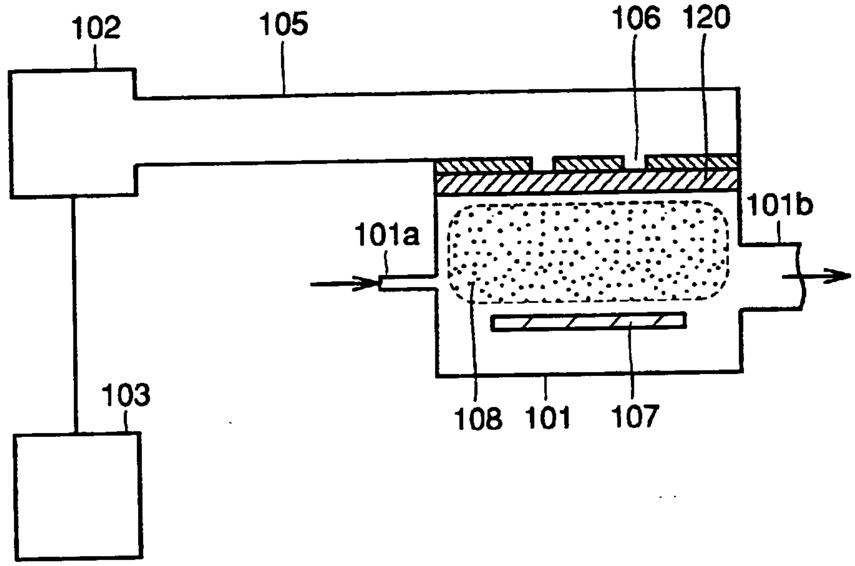

FIG. 22 PRIOR ART

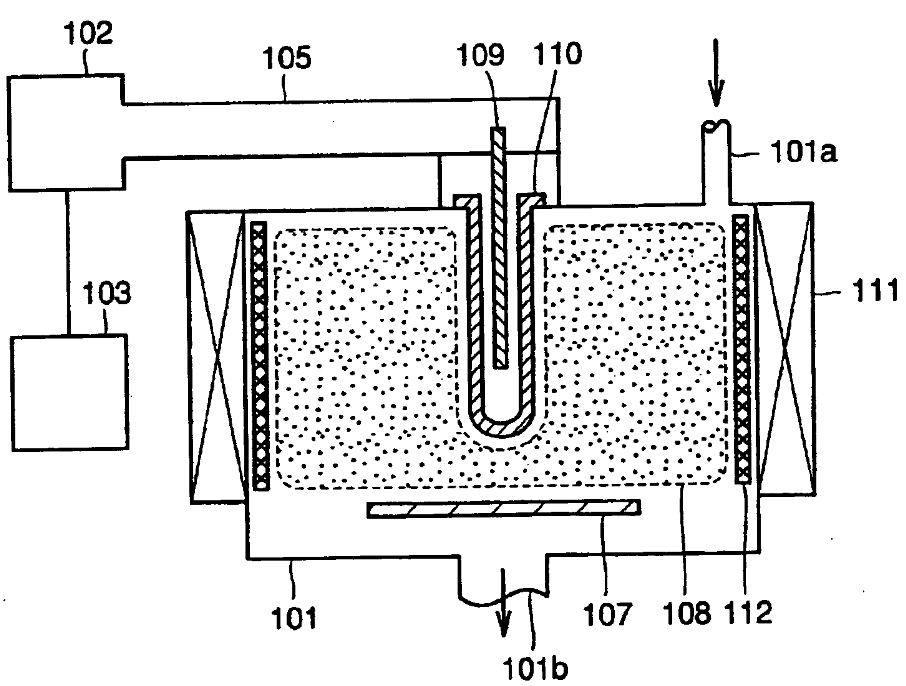

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FIG. 23 PRIOR ART

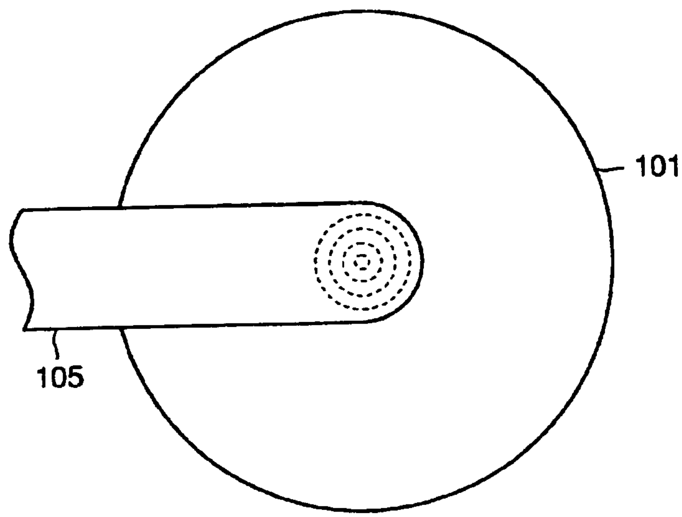
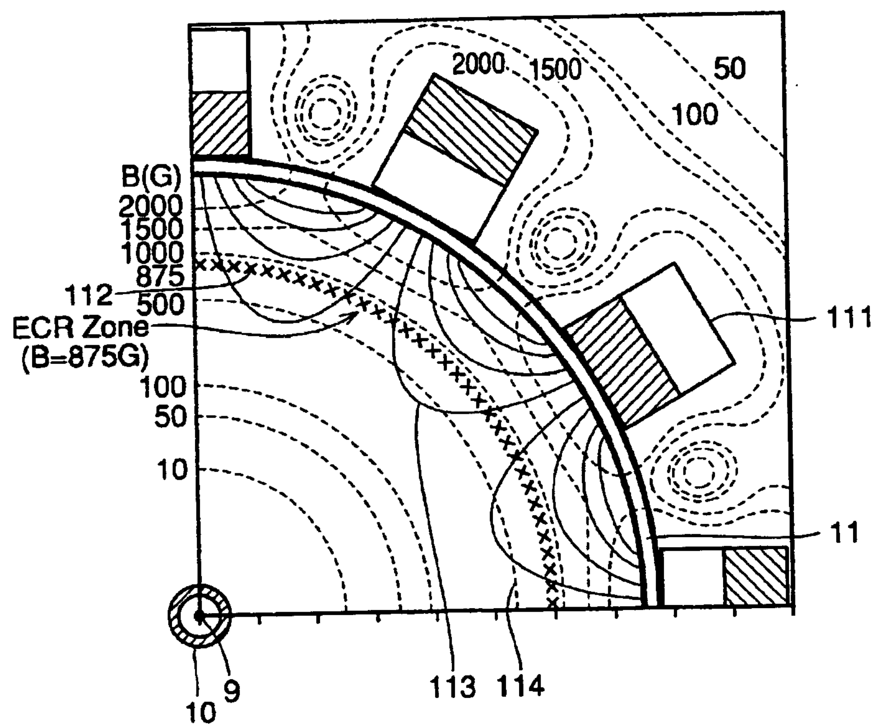


FIG. 24 PRIOR ART



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PLASMA GENERATING APPARATUS WITH MULTIPLE MICROWAVE INTRODUCING MEANS

CROSS-REFERENCE TO RELATED APPLICATION

This application is related to co-pending application of U.S. Ser. No. 09/031,706, filed Feb. 27, 1998, now U.S. Pat. No. 6,054,016, issued Apr. 25, 2000, commonly assigned to the same applicant.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a plasma generating apparatus and more particularly to a plasma generating apparatus for performing processings such as reforming, etching, ashing, cleaning and thin film formation at the surfaces of a semiconductor substrate, a liquid crystal glass substrate, an organic material, a metallic material or the like by using generated plasma.

2. Description of the Background Art

Plasma generating apparatuses for generating plasma by the electromagnetic energy of surface waves which are excited and propagated at a boundary of plasma and a surface of a dielectric used for introducing microwaves into a vacuum vessel have been used as a plasma generating apparatus using microwaves. A conventional plasma generating apparatus will be described below with reference to FIGS. 21–24.

As shown in FIG. 21, a surface wave plasma generating apparatus mainly used as a conventional plasma generating apparatus includes a vacuum vessel **101**, a microwave oscillator **102**, a driving power supply **103**, a waveguide **105** and a dielectric plate **120**. Vacuum vessel **101** has a gas supply port **101***a* for supplying a gas for discharging electrons (discharge gas) and a gas evacuation port **101***b* for evacuating the discharge gas which are provided in the vessel. A substrate **107** for various processings is placed on the lower side of the interior of vacuum vessel **101**. on the upper side of the interior of vacuum vessel **101** are provided with a slit **106** and a dielectric plate **120** placed immediately thereunder and formed of a dielectric material. Dielectric plate **120** is connected to waveguide **105**. Waveguide **105** is connected to microwave oscillator **102**. Further, microwave oscillator **102** is connected to driving power supply **103**.

The operation of the conventional surface wave plasma generating apparatus having the structure above will be described. First, a high vacuum pump (not shown) such as a roughing pump and a turbo-molecular pump connected to evacuation port **101***b* evacuates vacuum vessel **101** to a high vacuum, and a discharge gas such as argon, hydrogen, oxygen, chloride, carbon tetrafluoride and silane is supplied through gas supply port **101***a*. Thus, the interior of vacuum vessel **101** comes to have a prescribed pressure by the discharge gas. Then, microwave oscillator **102** oscillates microwaves by driving of driving power supply **103**. The microwaves are emitted to waveguide **105**. The microwaves pass through waveguide **105** and they are emitted from a microwave transmission circuit through slit **106**. The emitted microwaves pass through dielectric plate **120** located on an upper surface of vacuum vessel **101** and they are introduced into vacuum vessel **101**. Accordingly, plasma **108** is generated inside vacuum vessel **101**.

When the density of plasma **108** increases after generation of plasma **108**, the microwaves cannot progress into plasma

108. Therefore, they become surface waves generated on a surface of plasma **108** and they are guided in this form. The surface waves propagate along a boundary between dielectric plate **120** and plasma **108**. The microwaves are absorbed by plasma **108** being propagated. As a result, in the vicinity of the surface of dielectric plate **120**, electrons are accelerated by the vibrational electric field of the surface waves, attaining a high-energy state. The generated plasma **108** of high density is thus dispersed.

However, since dielectric plate **120** is located only on the upper side of vacuum vessel **101** in the conventional plasma generating apparatus as shown in FIG. **21**, there caused a difference in microwave introduction between the portions near and remote from dielectric plate **120**. It causes electrons and ions in plasma **108** to recombine together when dispersed. Thus, the distribution of the density of plasma **108** is made non-uniform in vacuum vessel **101**. As a result, a processing of substrate **107** is also made non-uniform. When vacuum vessel **101** is to be enlarged as the diameter of substrate **107** becomes larger, electrons and ions in plasma **108** are also easily recombined together, the distribution of plasma **108** cannot be kept uniform, and the processing of substrate **107** tends to be non-uniform. This may affect the function of a semiconductor device, preventing the larger diameter of substrate **107**.

In order to solve the problems above, the inventors proposed a plasma generating apparatus in which a dielectric tube **110** is inserted into vacuum vessel **101**, as shown in FIGS. **22** and **23**, as described in the co-pending application of U.S. Ser. No. 09/031,706, filed Feb. 27, 1998 now U.S. Pat. No. 6,054,016.

In the plasma generating apparatus, the vacuum vessel is of a column shape and dielectric tube **110** is arranged in the height direction. This allows uniform introduction of the microwaves in the height direction. The microwaves and a multi-cusp magnetic field **113** generated from magnets **111** shown in FIG. **24** serve to generate and maintain the plasma. It is therefore possible to allow a sufficiently uniform distribution of plasma **108** in the height direction of the column-shaped vacuum vessel.

However, since the apparatus shown in FIG. **22** has only one antenna **109** and one dielectric tube **110**, microwave energy hardly reaches near a wall of vacuum vessel **101**. Plasma **108** tends to disappear near the wall of vacuum vessel **101**. Therefore, the distribution of plasma **108** in the diameter direction of column-shaped vacuum vessel **101** is not sufficiently uniform, and plasma **108** which is completely uniform cannot be generated.

SUMMARY OF THE INVENTION

An object of the present invention is to improve the above mentioned co-pending application of U.S. Ser. No. 09/031,706, filed Feb. 27, 1998, now U.S. Pat. No. 6,054,016 and to provide a plasma generating apparatus capable of generating highly uniform plasma in both of the height direction and the diameter direction and stably supplying and maintaining the plasma of high density in a wide range.

A plasma generating apparatus according to one aspect of the present invention for achieving the object described above includes a microwave generating portion for generating microwaves, a microwave transmitting portion for guiding the microwaves generated by the microwave generating portion, a vacuum vessel connected to the microwave transmitting portion and having a portion for supplying a discharge gas and a vacuum evacuation portion, a microwave emitting portion for emitting the microwaves

guided from the microwave transmitting portion into the vacuum vessel, and a microwave introducing portion for introducing the microwaves emitted by the microwave emitting portion into the vacuum vessel, for generating plasma in a prescribed region including a plasma processing region in the vacuum vessel, the microwave emitting portion including a portion for emitting the microwaves for a plurality of locations in the vacuum vessel, and the microwave introducing portion including a portion for introducing the microwaves emitted from the microwave emitting portion to a plurality of parallel locations on the plasma processing region in the vacuum vessel.

By thus structuring the plasma generating apparatus according to the present invention, the microwave emitting portion includes a portion for emitting the microwaves to a plurality of locations parallel to the direction along the plasma processing region in the vacuum vessel, so that the microwaves are emitted for the plurality of locations on the plasma processing region and plasma is generated at the plurality of locations. Therefore, plasma having a more uniform density distribution in the direction along the plasma processing region can be generated than when the microwaves are emitted for only one location as in the prior art. Thus, the uniformity of a plasma-processing in the plasma processing region is improved, and a plasma generating apparatus can be provided which can cope with a larger diameter of a substrate as an object for the plasma processing.

Although a waveguide is mainly used as a microwave transmitting portion, it may be replaced by a flexible member such as a coaxial cable or a corrugated tube according to the degree of microwave power in order to simplify the structure of the plasma generating apparatus.

The microwave introducing portion may be structured by arranging a plurality of tube-shaped or rod-shaped dielectric members in parallel and inserting their respective ends into the vacuum vessel. According to this structure, a plurality of tube-shaped or rod-shaped dielectric members are arranged in parallel and inserted into the vacuum vessel, and microwave power from the microwave generating portion is dispersively introduced into the vacuum vessel. Therefore, a load on each dielectric member is reduced.

The microwave emitting portion may be a plurality of antennas each having one end coupled to the microwave transmitting portion and the other end inserted into each dielectric member. By inserting the ends of the antennas deep into the vacuum vessel, the location for emitting the microwaves is brought closer to a prescribed-plasma processing region, which easily increases the density of plasma in the plasma processing region. When a plurality of slits are provided instead of the antennas as the microwave emitting portion in a preferred embodiment, such an advantage is not achieved. However, it has a similar advantage in that the uniformity of the plasma density distribution in the plasma processing region is improved compared with a conventional plasma generating apparatus having one slit.

In a preferred embodiment of the plasma generating apparatus having a structure described above, a driving portion may further be provided which moves a part of the microwave emitting portion which emits the microwaves into the vacuum vessel in the vacuum vessel. According to the structure, the microwaves can be emitted at a plurality of locations parallel to the direction along a prescribed plasma processing region by using a microwave emitting portion such as an antenna formed of a single member, and the uniformity of the plasma density distribution in the plasma processing region can be improved by the microwave emitting portion having a simpler structure.

In another preferred embodiment of the plasma generating apparatus having a structure described above, a magnetic field generating portion may further be provided which generates a magnetic field in the vacuum vessel. The magnetic generating portion generates a multi-cusp magnetic field in the vicinity of an inner wall of the vacuum vessel, and plasma causes a cyclotron phenomenon by a magnetic mirror effect. Therefore, the plasma exists without colliding with the inner wall of the vacuum vessel. Thus, the generated plasma easily keeps its state. Therefore, the uniformity of the plasma processing in a desired plasma processing region is further improved, and it is also possible to cope with a larger diameter of a substrate as an object for the plasma processing.

Although quartz is typically used as a dielectric material forming the microwave introducing portion, other dielectric materials may also be applied. A preferable example is a dielectric material consisting of one or more materials selected from the group of high molecular materials such as quartz, Pyrex glass and Teflon, and ceramics.

In another preferred embodiment of the plasma generating apparatus according to the present invention, the microwave transmitting portion has a microwave distribution portion for distributing the microwaves generated from the microwave generating portion to supply power to the microwave emitting portion, so that the microwaves can be introduced to a plurality of parallel locations on the plasma processing region.

In still another preferred embodiment of the plasma generating apparatus according to the present invention, the microwave emitting portion may include a portion for successively and selectively switching the location for emitting the microwaves among a plurality of locations. By including such a switching portion, the microwave emitting portion can successively emit, in a time-divisional manner, the microwaves for a plurality of locations to which the microwave are emitted. By thus emitting the microwaves, microwaves having limited power generated by one power supply are concentrated and emitted at one location. As a result, the density of plasma generated at the location can be increased. In this case, there is a difference in the density of plasma newly generated at respective locations from the viewpoint of each divided time. However, the plasma once generated does not attenuate soon but it maintains a certain density even when emission of the microwaves is stopped. Therefore, plasma of high density and high uniformity can be generated in a desired plasma producing region.

As the portion for successively and selectively switching the location for emitting the microwaves, the microwave transmitting portion can have a microwave distributing portion for distributing the microwaves generated from the microwave generating portion to supply power to the microwave emitting portion, and the microwave distributing portion can include a switching portion for switching a microwave emitting portion to be supplied with the microwaves among a plurality of microwave emitting portions. As another example of the portion for successively and selectively switching the location for emitting the microwaves, the microwave emitting portion can include a plurality of slits which are opened near one end of the microwave introducing portion, and a shutter for selectively shutting the plurality of slits to switch a slit for emitting the microwaves between the plurality of slits.

The foregoing and other objects, features, aspects and advantages of the present invention will become more

apparent from the following detailed description of the present invention when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a schematic structure of a plasma generating apparatus according to a first embodiment of the present invention.

FIG. 2 is a plan view in the neighborhood of a vacuum vessel of the plasma generating apparatus shown in FIG. 1.

FIG. 3 shows the arrangement of permanent magnets and the distribution of the strength of a generated magnetic field in the first embodiment of the present invention.

FIG. 4 shows one variation of an antenna of the plasma generating apparatus according to the first embodiment of the present invention.

FIG. 5 shows another variation of an antenna of the plasma generating apparatus according to the first embodiment of the present invention.

FIG. 6 shows still another variation of an antenna of the plasma generating apparatus according to the first embodiment of the present invention.

FIG. 7 shows a schematic structure of one variation of the plasma generating apparatus according to the first embodiment of the present invention.

FIG. 8 shows a schematic structure of another variation of the plasma generating apparatus according to the first embodiment of the present invention.

FIG. 9 shows a schematic structure of still another variation of the plasma generating apparatus according to the first embodiment of the present invention.

FIG. 10 shows a schematic structure of a plasma generating apparatus according to a second embodiment of the present invention.

FIG. 11 is a plan view in the neighborhood of a vacuum vessel of the plasma generating apparatus shown in FIG. 10.

FIG. 12 is a plan view showing an overall schematic structure of a plasma generating apparatus according to a third embodiment of the present invention.

FIG. 13 is a schematic diagram of distributor 30 when switches 35 and 36 are ON and OFF, respectively, in the third embodiment of the present invention.

FIG. 14 is a schematic diagram of distributor 30 when switches 35 and 36 are OFF and ON, respectively, in the third embodiment of the present invention.

FIG. 15 shows pulses for controlling switches 35 and 36 of distributor 30 in the third embodiment of the present invention.

FIG. 16 shows plasma generation when switches 35 and 36 of distributor 30 are OFF and ON, respectively, in the third embodiment of the present invention.

FIG. 17 shows plasma generation when switches 35 and 36 of distributor 30 are ON and OFF, respectively, in the third embodiment of the present invention.

FIG. 18 shows plasma generation when switches 35 and 36 of the distributor are both ON in the third embodiment of the present invention.

FIG. 19 shows a schematic structure of one variation of the plasma generating apparatus according to the third embodiment of the present invention.

FIG. 20 is a plan view in the neighborhood of a vacuum vessel of the plasma generating apparatus shown in FIG. 19.

FIG. 21 shows a schematic structure of a conventional plasma generating apparatus.

FIG. 22 shows a schematic structure of the plasma generating apparatus proposed by the inventors in the above described co-pending application of U.S. Ser. No. 09/031,706, filed Feb. 27, 1998, now U.S. Pat. No. 6,054,016.

FIG. 23 is a plan view in the neighborhood of a vacuum vessel of the plasma generating apparatus shown in FIG. 21.

FIG. 24 shows the arrangement of permanent magnets and the distribution of the strength of a generated magnetic field in the plasma generating apparatus shown in FIG. 21.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The embodiments of the present invention will be described below with reference to the drawings.

(First Embodiment)

A first embodiment of the present invention will be described based on FIGS. 1–3. As shown in FIGS. 1 and 2, a plasma generating apparatus includes a vacuum vessel **1**, a microwave oscillator **2**, a driving power supply **3** and a waveguide **5**. Further, vacuum vessel **1** has a gas supply port **1***a* for supplying a discharge gas into vacuum vessel **1** and a gas evacuation port **1***b* for evacuating vacuum vessel **1** to obtain a vacuum state. A substrate **7** to be processed is placed on a lower side of the interior of vacuum vessel **1**. On an upper side of the interior of vacuum vessel **1** are provided with four rod antennas **9***a*, **9***b*, **9***c*, **9***d* and four dielectric tubes **10***a*, **10***b*, **10***c*, **10***d* in which one end of respective rod antennas **9***a*, **9***b*, **9***c*, **9***d* are inserted. Dielectric tubes **10***a*, **10***b*, **10***c*, **10***d* are connected to waveguide **5**. Waveguide **5** is connected to microwave oscillator **2**. Further, microwave oscillator **2** is connected to driving power supply **3**.

Permanent magnets **11** are located around vacuum vessel **1**. Permanent magnets **11** generate a cyclotron resonance region **12** where magnetic strength is about 875 G for microwaves having a frequency of 2.45 GHz, for example, in a magnetic field region where the frequency of microwaves coincides with the cyclotron frequency of electrons. Permanent magnets **11** also generate a so-called multi-cusp magnetic field **13** which is a magnetic field generated between a plurality of N and S poles of permanent magnets. The distribution of magnetic fields are as specified by equal magnetic field strength lines **14** for permanent magnet **11**. Rod antennas **9***a*, **9***b*, **9***c*, **9***d* and dielectric tubes **10***a*, **10***b*, **10***c*, **10***d* for introducing microwaves into vacuum vessel **1** are located inside vacuum vessel **1**, and magnetic strength at the microwave introduction portion is within 100 G as shown in FIG. 3. In this structure, plasma **8** is produced in vacuum vessel **1**.

As shown in FIG. 2, a T branch having branch portions **20***a*, **20***b*, **20***c* is connected to waveguide **5**. Microwaves are distributed from waveguide **5** to rod antennas **9***a*, **9***b*, **9***c*, **9***d* so that the microwaves are firstly guided to branch portion **20***a* connected to waveguide **5**, secondly branched off in two directions from branch portion **20***a* toward branch portions **20***b* and **20***c*, and thirdly branched off from the both ends of the branching sides of branch portion **20***a* to branch portions **20***b* and **20***c*. Thereafter, the microwaves are guided to rod antennas **9***a*, **9***b*, **9***c*, **9***d* connected to the both ends of respective branch portions **20***b* and **20***c*. The microwaves are thus emitted from rod antennas **9***a*, **9***b*, **9***c*, **9***d* into vacuum vessel **1**. Here, dielectric tubes **10***a*, **10***b*, **10***c*, **10***d* are made of quartz, they separate the vacuum atmosphere from the atmosphere, and can pass the microwaves to be introduced into vacuum vessel **1**.

The operation of the thus structured plasma generating apparatus in this embodiment will be described below.

First, a high vacuum pump (not shown) such as a roughing pump and a turbo-molecular pump connected to evacu-

ation port $1b$ as in the conventional structure evacuates vacuum vessel 1 to a high vacuum, and a discharge gas such as argon, hydrogen, oxygen, chloride, carbon tetrafluoride and silane is supplied through gas supply port $1a$. Thus, the interior of vacuum vessel 1 reaches a prescribed pressure by the discharge gas. Thereafter, microwave oscillator 2 oscillates microwaves by driving of driving power supply 3. The microwaves are guided to waveguide 5. The microwaves pass through waveguide 5 and they are distributed into four directions by branch portions 20a, 20b and 20c. Then, the microwaves which were guided through waveguide 5 are emitted from a microwave transmission circuit by rod antennas 9a, 9b, 9c, 9d coupled to branch portions 20b and 20c. Thereafter, the emitted microwaves pass through dielectric tubes 10a, 10b, 10c, 10d inserted into vacuum vessel 1 and they are introduced into vacuum vessel 1. At this time, in the vicinity of an electron cyclotron resonance region 12 generated by permanent magnets 11, the frequency of the microwaves coincides with the cyclotron frequency of electrons, which causes an electron cyclotron resonance phenomenon in which electrons are resonantly accelerated by the vibrational electric field of the microwaves. Thus, electron cyclotron resonance discharging is easily caused under a low gas pressure in the order of 10^{-4} Torr, and plasma 8 is generated in vacuum vessel 1.

Microwave power being introduced is small after plasma 8 is generated. If the density of electrons is lower than a so-called cutoff density of microwaves (about 7×10^{10} cm^{-3} in the case of microwaves having a frequency of 2.45 GHz) which is a borderline as to whether microwaves can be introduced into plasma 8 or not, the microwaves introduced into vacuum vessel 1 through dielectric tubes 10a, 10b, 10c, 10d can propagate through plasma 8 and reach electron cyclotron resonance region 12. Therefore, resonated electrons which obtain energy from the electron cyclotron resonance excite, dissociate and electrically dissociate neutral gas particles on atoms or molecules and maintain generation of plasma 8.

If microwave power being introduced is large and the density of electrons in plasma 8 is higher than the cutoff density, the microwaves which were introduced through dielectric tubes 10a, 10b, 10c, 10d into vacuum vessel 1 cannot propagate through plasma 8 and can exist as surface waves propagating only along a boundary between dielectric tubes 10a, 10b, 10c, 10d and plasma 8. Even in the case of plasma of high density in which the density of electrons in plasma 8 exceeds the cutoff density, the excited surface waves propagate along the boundary without being reflected, and the energy is absorbed by plasma 8 during propagation. Therefore, electrons in plasma 8 in the vicinity of the surfaces of dielectric tubes 10a, 10b, 10c, 10d are accelerated by the vibrational electric field of the surface waves and they attain a high-energy state. Thus, they excite, dissociate and electrically dissociate neutral gas particles on atoms or molecules and maintain generation of plasma 8.

As shown in FIG. 3, permanent magnets 11 attached around vacuum vessel 1 form multi-cusp magnetic field 13 in the vicinity of a wall surface of vacuum vessel 1. Multi-cusp magnetic field 13 causes a so-called magnetic mirror effect and acts to confine electrons or ions in plasma 8 to vacuum vessel 1. Especially, multi-cusp-magnetic field 13 can increase a magnetic mirror rate for electrons or ions generated in a low magnetic field region at the center of vacuum vessel 1, providing an extremely strong magnetic confinement effect. By the effect of multi-cusp magnetic field 13, the loss of plasma 8 in the recombination process on the wall surface of vacuum vessel 1 can be suppressed and generated plasma 8 can easily be maintained.

Since rod antennas 9a, 9b, 9c, 9d and dielectric tubes 10a, 10b, 10c, 10d for introducing the microwaves into vacuum vessel 1 are located in the low magnetic field region, the magnetic mirror rate can be increased for electrons or ions generated by the power of the surface waves which are excited and propagated at the boundary of dielectric tubes 10a, 10b, 10c, 10d and plasma 8. Thus, the magnetic confinement effect which acts on the charged particles is significantly strong.

In other words, by the combination of generation of plasma 8 due to excitement of the surface waves in the low magnetic field region and confinement of the plasma by multi-cusp magnetic field 13, plasma 8 of high density which exceeds the cutoff density can be produced efficiently even under a low gas pressure in the order of 10^{4} Torr. Conventionally, rod antenna 109 and dielectric tube 110 have been provided to introduce microwave power into vacuum vessel 101 from one location as shown in FIG. 22. In this embodiment, however, rod antennas 9a, 9b, 9c, 9d and dielectric tubes 10a, 10b, 10c, 10d introduce microwave power to the low magnetic field region in vacuum vessel 1 from four locations. Thus, microwaves are supplied into vacuum vessel 1 from dielectric tubes 10a, 10b, 10c, 10d at four locations which are disposed as a whole compared with the case of one location. Thus, the microwaves are dispersed and uniformly supplied in the height direction and the diameter direction. Therefore, the uniformity of the plasma density is improved, suppressing decrease of the plasma density which is caused by recombination of electrons and ions in plasma 8 dispersing in the diameter direction. In this embodiment, a uniform processing is thus made possible for substrate 7 provided in vacuum vessel 1. When a semiconductor device is provided on substrate 7 and thin film formation, for example, by the plasma CVD method is performed the processing can be performed with a uniform plasma distribution. Thus, improvement in yield can be expected.

Although quartz is used as a dielectric material in this embodiment, uniform plasma generation is allowed even if quartz is replaced by one or more materials selected from the group of high molecular materials such as Pyrex glass and Teflon, and ceramics.

Although rod antennas 9a, 9b, 9c, 9d, are used to emit microwaves from the microwave transmission circuit in this embodiment, any antenna structure which can emit microwaves such as a spiral antenna as shown in FIG. 4, a helical antenna as shown in FIG. 5, a lisitano coil as shown in FIG. 6 and a loop antenna (not shown) can also have the effect that the uniformity of plasma is improved. Further, the effect that the uniformity of plasma is improved can also be achieved even by combining the antenna structures as necessary.

Although the number of rod antennas 9a, 9b, 9c, 9d and dielectric tubes 10a, 10b, 10c, 10d for introducing microwaves is 4 as an example in this embodiment, the number does not need to be 4. By introducing microwaves from at least more than one location, the uniformity of plasma can be improved.

Although dielectric tubes are used in this embodiment, dielectric rods 10a, 10b, 10c, 10d having antennas 9a, 9b, 9c, 9d buried into a dielectric may be employed. Even when antennas 9a, 9b, 9c, 9d as microwave emitting means are not used and dielectric tubes or dielectric rods 10a, 10b, 10c, 10d are provided under slits and connected to the waveguide as shown in FIGS. 8 and 9, the uniformity of plasma 8 can also be improved.

Although permanent magnets 11 are used to generate, as multi-cusp magnetic field 13, a line-cusp magnetic field as

shown in FIG. 3 in this embodiment, any distribution of magnetic field strength forming a strong magnetic field region in the vicinity of a wall surface of vacuum vessel 1 and forming a low magnetic field region at the center of vacuum vessel 1 to which microwaves are introduced, such as a ring-cusp magnetic field or a compound-cusp magnetic field, can achieve the same effect.

Although waveguide 5 and branch portions 20a, 20b, 20c are provided as means for supplying power from microwave oscillator 2 in this embodiment, the same effect can be achieved even by using a coaxial cable or a corrugated tube instead.

Further, the structure capable of achieving the same effect can be realized even by combining the waveguide, the coaxial cable, the corrugated tube as necessary.

(Second Embodiment)

A second embodiment of the present invention will be described below with reference to FIGS. 10–13.

As shown in FIG. 10, the plasma generating apparatus includes vacuum vessel 1, microwave oscillator 2, driving power supply 3 and waveguide 5. Further, vacuum vessel 1 has gas supply port 1a for supplying a discharge gas and gas evacuation port 1b for evacuating the discharge gas inside the vessel. Substrate 7 to be processed is placed on a lower side of the interior vacuum vessel 1. On an upper side of vacuum vessel 1 is provided with a driving device 25 capable of rotating, in vacuum vessel 1, one rod antenna 9 and dielectric tube 10 into which one end of rod antenna 9 inserted. The upper end of dielectric tube 10 is connected to one end of waveguide 5, and the other end of waveguide 5 is connected to microwave oscillator 2 supplied with power from driving power supply 3.

Permanent magnets 11 are located around vacuum vessel 1. Permanent magnets 11 generate cyclotron resonance region 12 where magnetic strength is about 875 G for microwaves having a frequency of 2.45 GHz, for example, in a magnetic region where the frequency of microwaves coincides with the cyclotron frequency of electrons. Permanent magnets 11 also generate multi-cusp magnetic field 13 and equal magnetic field strength lines 14. Rod antenna 9 and dielectric tube 10 for introducing microwaves into vacuum vessel 1 are located inside vacuum vessel 1, and magnetic strength at the microwave introduction portion is within 100 G as shown in FIG. 3. In this structure, plasma 8 is produced in vacuum vessel 1. Rod antenna 9 emits microwaves from the microwave transmission circuit. Dielectric tube 10 is made of quartz, they separate the vacuum atmosphere from the atmosphere, and can pass microwaves to be introduced into vacuum vessel 1.

Since the operation of the plasma generating apparatus in this embodiment is almost the same as the plasma generating apparatus in the first embodiment until the microwaves are guided to rod antenna 9 and dielectric tube 10, the description will not be repeated. After the microwaves are guided to rod antenna 9 and dielectric tube 10, the microwaves are introduced from dielectric tube 10 into vacuum vessel 1 as in the first embodiment. At this time, however, dielectric tube 10 is rotated in vacuum vessel 1 by driving device 25 as shown in FIGS. 10 and 11. Therefore, the microwave introduction portion rotates in vacuum vessel 1 and accordingly the plasma generation portion rotates. In a conventional plasma generating apparatus, rod antenna 109 and dielectric tube 110 are provided to introduce microwave power from one fixed location to vacuum vessel 101 as shown in FIG. 22. In this embodiment, however, one rod antenna 9 and dielectric tube 10 capable of rotating are introduced in a low magnetic field region in vacuum vessel 1. Therefore, the microwave generation portion moves with the passage of time. Thus, the microwaves are controlled in a time-divisional manner and uniformly supplied not only in the height direction but in the diameter direction. Therefore, the uniformity of the plasma density is improved, suppressing decrease of the plasma density which is caused by recombination of electrons and ions in plasma 8 dispersing in the diameter direction. Since the uniformity of plasma 8 in vacuum vessel 1 is improved in this embodiment, an uniform processing can be performed for substrate 7 provided in vacuum vessel 1. When a semiconductor device is provided on substrate 7 and subjected to a film formation processing by the plasma CVD method, for example, an uniform plasma distribution is available. Thus, improvement in yield can be expected.

(Third Embodiment)

A third embodiment of the present invention will be described below with reference to FIGS. 12–20.

As shown in FIG. 12, a device for controlling supply of microwave power in the plasma generating apparatus according to this embodiment has a branching unit 30 which is connected to waveguide 5 and has means for distributing the microwave power. Branching unit 30 is connected to waveguides 5e and 5f and it supplies the microwave power to rod antennas 9e and 9f. Rod antennas 9e and 9f are connected to waveguides 5e and 5f, and they emit the microwave power from the microwave transmission circuit. The microwave power emitted from rod antennas 9e and 9f pass through dielectric tubes 10e and 10f. Dielectric tubes 10e and 10f are made of quartz, they separate the vacuum atmosphere from the atmosphere, and can pass microwaves to be introduced into vacuum vessel 1.

FIGS. 13 and 14 schematically show branching unit 30 described in connection with the method for supplying microwave power in this embodiment. In branching unit 30, switches 35 and 36 are provided which are switching means for turning ON/OFF supply of the microwave power. Further, a controller 31 is provided being connected to branching unit 30, and it controls ON/OFF of switches 35 and 36 provided in branching unit 30 with the waveform for switching operation as shown in FIG. 15. FIGS. 16 an 17 show the relation between the operation of branching unit 30 in FIGS. 13 and 14 and the generated plasma.

The operation of the thus structured plasma generating apparatus in this embodiment will be described below. Since the method for generating and maintaining plasma is the same as the first embodiment, the description will not be repeated. Here, the method for supplying microwave power to vacuum vessel 1 will be described.

From microwave oscillator 2, the microwave power is guided through waveguide 5 to branching unit 30. The microwave power guided to branching unit 30 is distributed into two directions when controller 31 turns ON switches 35 and 36 in branching unit 30. The microwave power which is distributed into two directions is introduced through waveguides 5e and 5f connected to branching unit 30 and through rod antennas 9e and 9f connected to waveguides 5e and 5f into vacuum vessel 1. Thus, the plasma as shown in FIG. 18 is generated.

Although branching unit 30 distributes the microwave power into two directions in this embodiment, the number of directions for distribution can be changed as necessary by using a branching unit which distributes the microwave power into an arbitrary number of directions such as three directions or four directions.

Although waveguides 5, 5e, 5f are used as means for supplying power from microwave oscillator 2 in this

embodiment, a coaxial cable or a corrugated tube can be used to distribute microwaves. Microwaves can also be distributed even by combining waveguide **5** with the coaxial cable and the corrugated tube as necessary.

In this embodiment, the microwave power is simultaneously distributed and supplied from branching unit **30** to waveguides **5e** and **5f**. However, the location for oscillating the microwave power can be switched as necessary by controlling switches **35** and **36** in branching unit **30**, as necessary, using controller **31** as shown in FIGS. **16–18** with the waveform for switching operation as shown in FIG. **15**. Further, by alternately switching between switches **35** and **36** as shown in FIGS. **13** and **14**, plasma **8** generated in vacuum vessel **1** is alternately generated in the periphery of rod antennas **9e** and **9f** as shown in FIGS. **16** and **17**. Therefore, plasma **8** is formed which is not uniform for an instant but is uniform within a constant unit time. Further, power per rod antenna can be increased compared with a case in which two rod antennas **9e** and **9f** are simultaneously discharged. As a result, energy for introducing the microwave power per dielectric tube can be increased when antennas are alternately discharged in a time-divisional manner if a power supply with the same power is used. Thus, plasma of higher density can be generated when strong energy of microwaves is alternately generated at one location in a time-divisional manner than when weak energy of microwaves is simultaneously introduced to two locations.

In this embodiment, a polar contact method of a relay type has been described as switches **35** and **36** in branching unit **30**. By using a contactless method such as a stub type, plasma of high density can also be generated in a time-divisional manner. Although one microwave oscillator **2** is used together with branching unit **30** for distribution and supplying in this embodiment, a microwave oscillator and a waveguide is connected to each one of a plurality of waveguides connected to a vacuum vessel.

In this embodiment, microwaves are distributed by using a T branch and an antenna. However, in order to distribute microwaves, a plurality of slits and corresponding dielectric members may be fixed, and the slits may be controlled so that they are opened successively in a time-divisional manner by a shutter. Plasma of high density can also be generated in this manner. An example of such a variation is shown in FIGS. **19** and **20**. Slits **6a, 6b, 6c, 6d** are provided above dielectric tubes **10a, 10b, 10c, 10d**, and a shutter **26** for opening only one of slits **6a, 6b, 6c, 6d** and closing others is provided on the upper surface of vacuum vessel **1**. Slits **6a, 6b, 6c, 6d** are successively opened by rotating shutter **26** in the direction denoted by arrow A in FIG. **20**.

Although the present invention has been described and illustrated in detail, it is clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of the present invention being limited only by the terms of the appended claims.

What is claimed is:

1. A plasma generating apparatus for generating plasma in a prescribed region including a plasma processing region, comprising:

a vacuum vessel having said plasma processing region therein and equipped with a vacuum evacuation means;

a discharge gas supplying means for supplying a discharge gas into said vacuum vessel;

a microwave emitting means for emitting microwaves into said vacuum vessel;

a microwave introducing means for introducing microwaves emitted by said microwave emitting means into said vacuum vessel; and

a magnetic field generating means for generating a magnetic field in said vacuum vessel;

wherein said microwave introducing means includes a plurality of tube-shaped or rod-shaped dielectric members arranged in parallel and inserted into said vacuum vessel; and

said magnetic field generating means includes a means for generating a magnetic field strong enough for creating an electron cyclotron resonance region with microwaves having a prescribed frequency in the vicinity of an inner wall of said vacuum vessel and a means for generating a magnetic field of less than or equal to 100 G in the region where said plurality of tube-shaped or rod-shaped dielectric members of said microwave introducing means are located.

2. The plasma generating apparatus according to claim **1**, wherein

said microwave emitting means has a plurality of antennas each having one end coupled to said microwave transmitting means and another end inserted into each said dielectric member.

3. The plasma generating apparatus according to claim **1**, wherein

said microwave emitting means includes a slit which is opened near said one end of said dielectric member.

4. The plasma generating apparatus according to claim **1**, further comprising:

driving means for moving, in said vacuum vessel, a portion of said microwave emitting means for emitting the microwaves into said vacuum vessel and said microwave introducing means.

5. The plasma generating apparatus according to claim **1**, wherein

said microwave transmitting means has microwave distributing means for distributing the microwaves generated from said microwave generating means to supply power to said microwave emitting means.

6. The plasma generating apparatus according to claim **1**, wherein

said microwave emitting means includes means for successively and selectively switching a location for emitting the microwaves among said plurality of locations.

7. The plasma generating apparatus according to claim **6**, wherein

said microwave transmitting means has microwave distributing means for distributing the microwaves generated from said microwave generating means to supply power to a plurality of said microwave emitting means, and said microwave distributing means includes switching means for switching microwave emitting means to be supplied with the microwaves among the plurality of said microwave emitting means.

8. The plasma generating apparatus according to claim **6**, wherein

said microwave emitting means includes a plurality of slits being opened near one end of said microwave introducing means and a shutter for selectively shutting the plurality of slits to switch a slit for emitting the microwaves among said plurality of slits.

* * * * *

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(12) **United States Patent**
Ishii et al.

(10) **Patent No.: US 6,322,662 B1**
(45) **Date of Patent: Nov. 27, 2001**

(54) **PLASMA TREATMENT SYSTEM**

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(73) Assignees: **Tokyo Electron Limited**, Tokyo; **Makoto Ando**, Kanagawa-ken; **Naohisa Goto**, Tokyo, all of (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/494,031**

(22) Filed: **Jan. 31, 2000**

(30) **Foreign Application Priority Data**

Feb. 1, 1999 (JP) 11-023454

(51) **Int. Cl.**[7] **H05H 1/00**; C23C 16/00

(52) **U.S. Cl.** .... **156/345**; 118/723 MW; 118/723 AN

(58) **Field of Search** .... 156/345; 118/723 MW, 118/723 ME, 723 MR, 723 E, 723 AN

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,342,472 * 8/1994 Imahashi et al. 204/298.38
5,545,258 * 8/1996 Katayama et al. .... 118/723 MP
5,698,036 12/1997 Ishii et al. .
5,804,923 * 9/1998 Iio et al. 315/111.21
5,874,706 * 2/1999 Ishii et al. 219/121.43
5,911,852 * 6/1999 Katayama et al. 156/345
5,951,887 * 9/1999 Mabuchi et al. 219/121.43
5,988,104 * 11/1999 Nambu .... 118/723 MW

FOREIGN PATENT DOCUMENTS

8-111297 4/1996 (JP) .
9-181052 * 7/1997 (JP) C23C/16/00

* cited by examiner

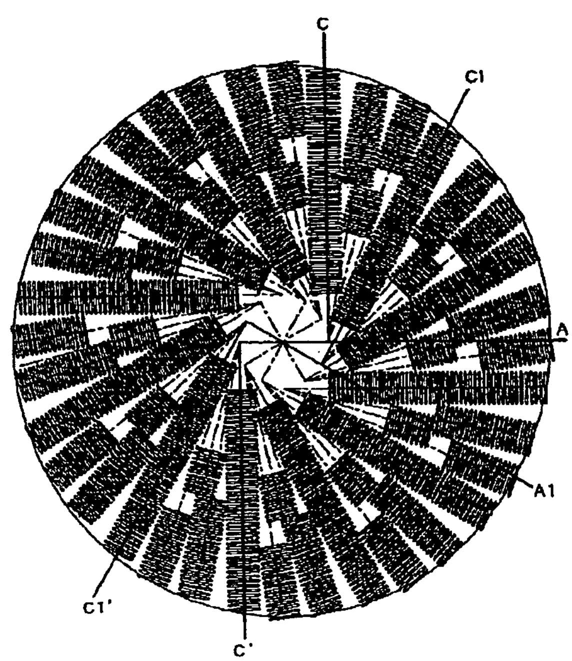
Primary Examiner—Gregory Mills
Assistant Examiner—P. Hassanzadeh
(74) *Attorney, Agent, or Firm*—Finnegan, Henderson, Farabow, Garrett & Dunner LLP

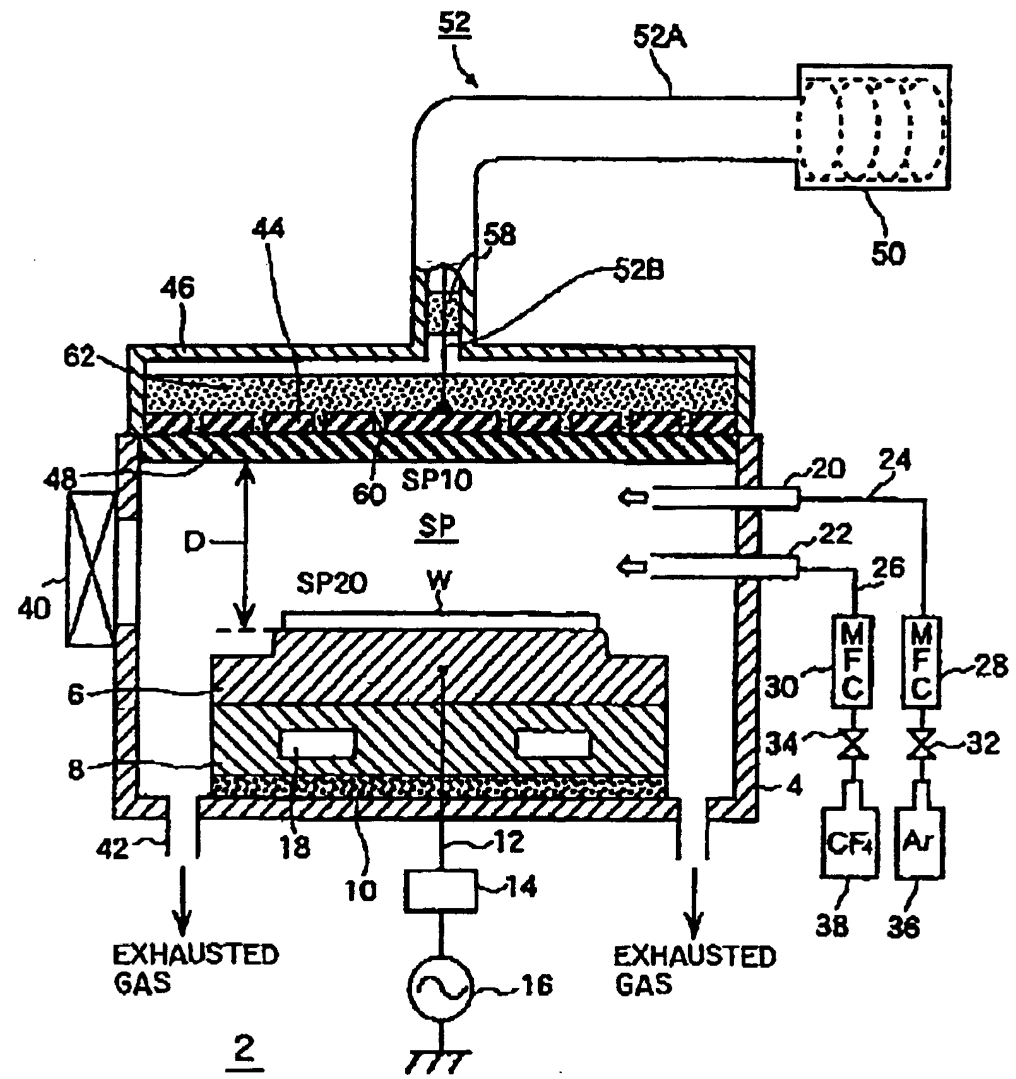
(57) **ABSTRACT**

In a plasma treatment system, the increase of the electric field of a treatment space facing the central portion of a flat antenna member is relieved, and the ununiformity of the density of plasma in a plasma forming region is relieved.

Microwave generated by a microwave generator **50** are supplied from a waveguide **52** to a flat antenna member **44**. The flat antenna member **44** has a plurality of slots **60**. The space between adjacent two of the slots **60** is longer than the guide wavelength of microwaves in the waveguide **52**, and the length of each of the slots **60** is shorter than half of the guide wavelength. The slots **60** are arranged in a region other than the central portion of the flat antenna member **44** so as not to be axisymmetric.

6 Claims, 15 Drawing Sheets




52
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52B
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M
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C
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28
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34
32
8
4
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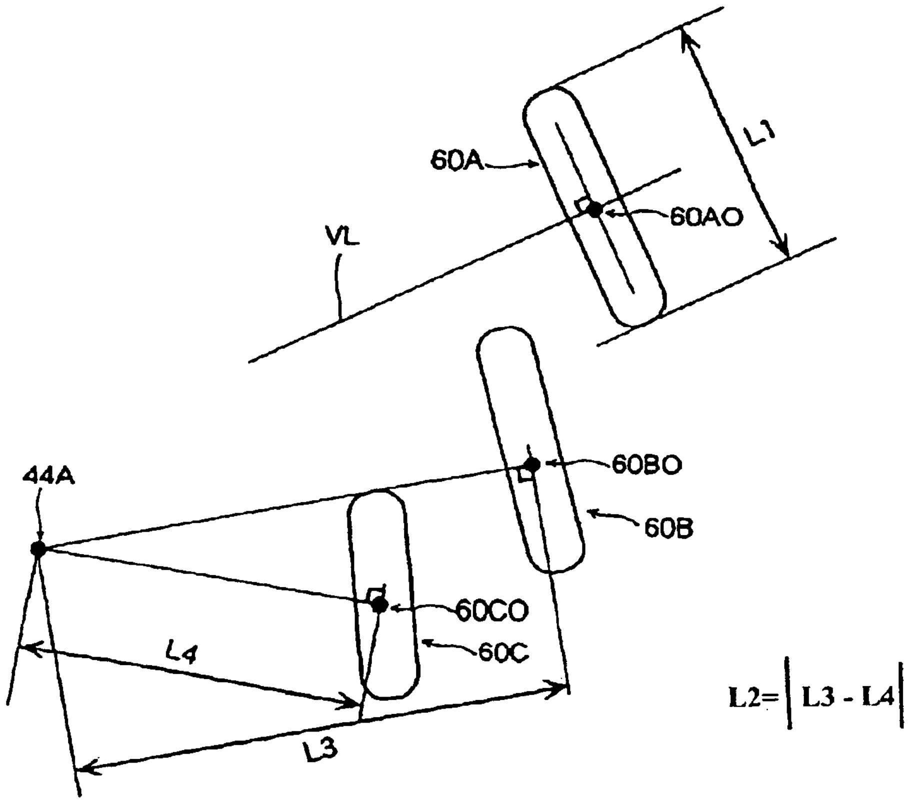
EXHAUSTED
GAS
16
EXHAUSTED
GAS
2

FIG. 1



F I G. 2

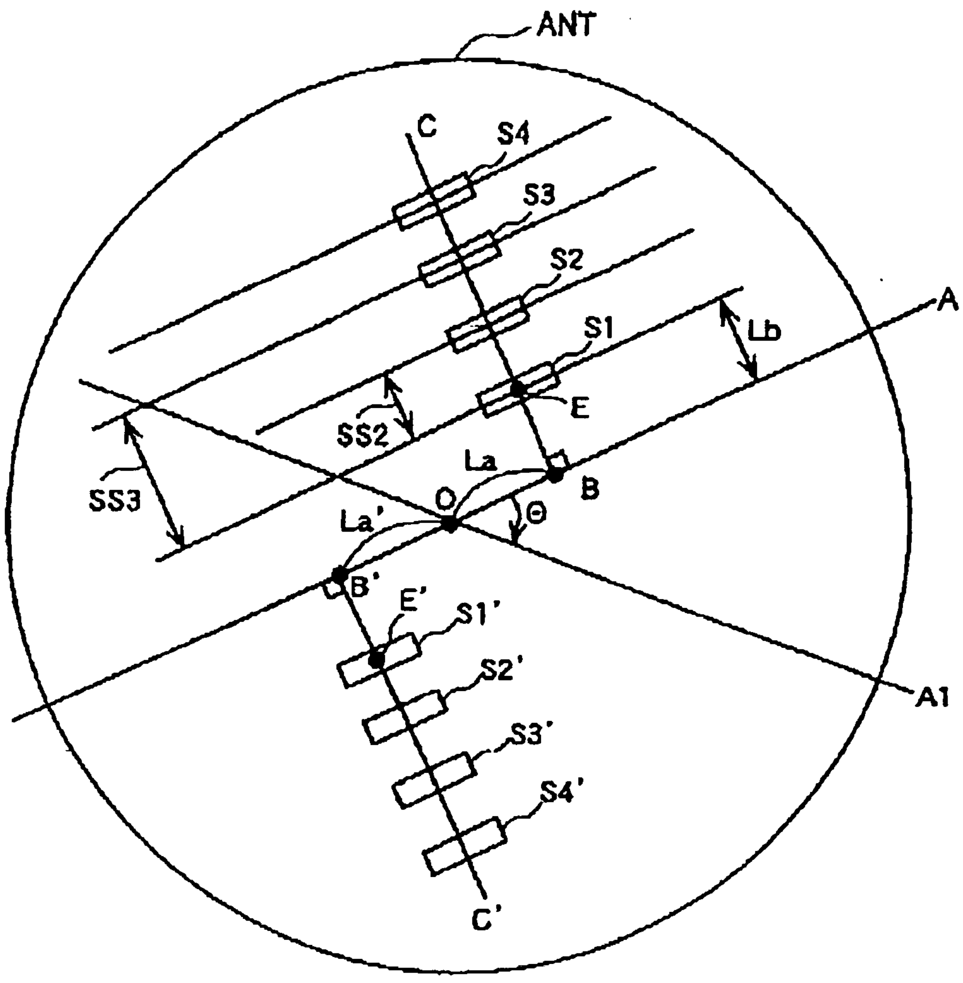


FIG. 3

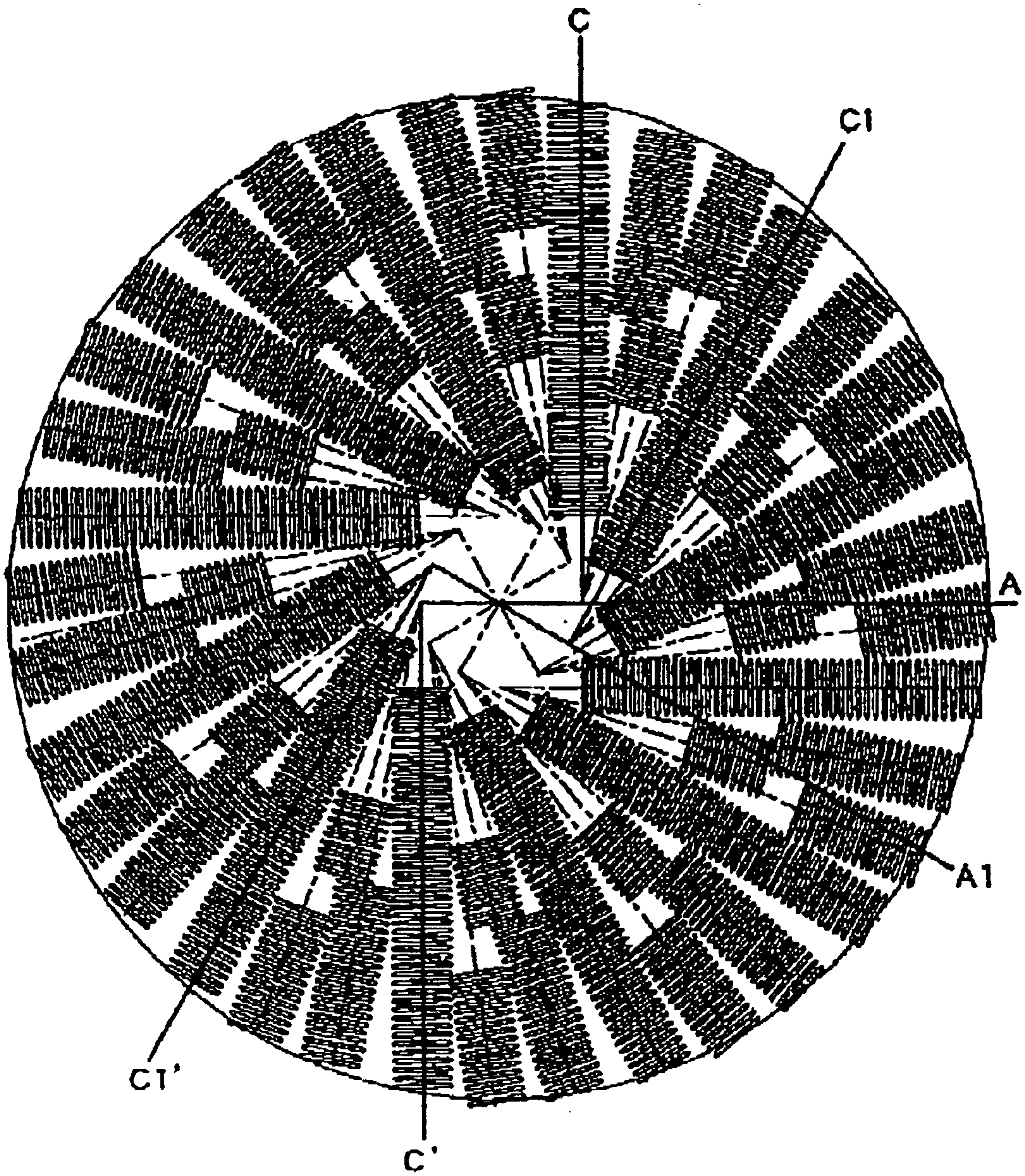


FIG. 4

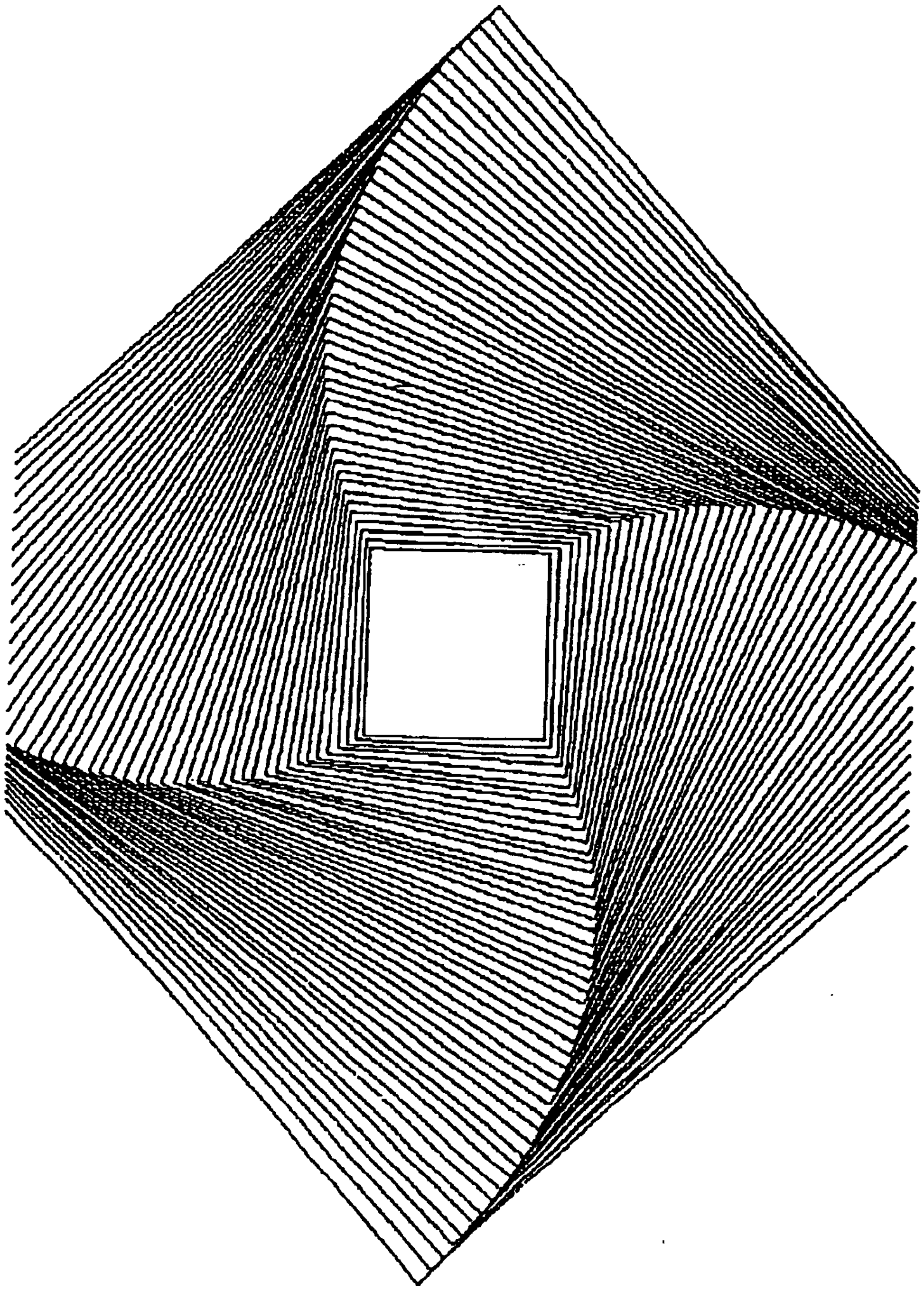


FIG. 5

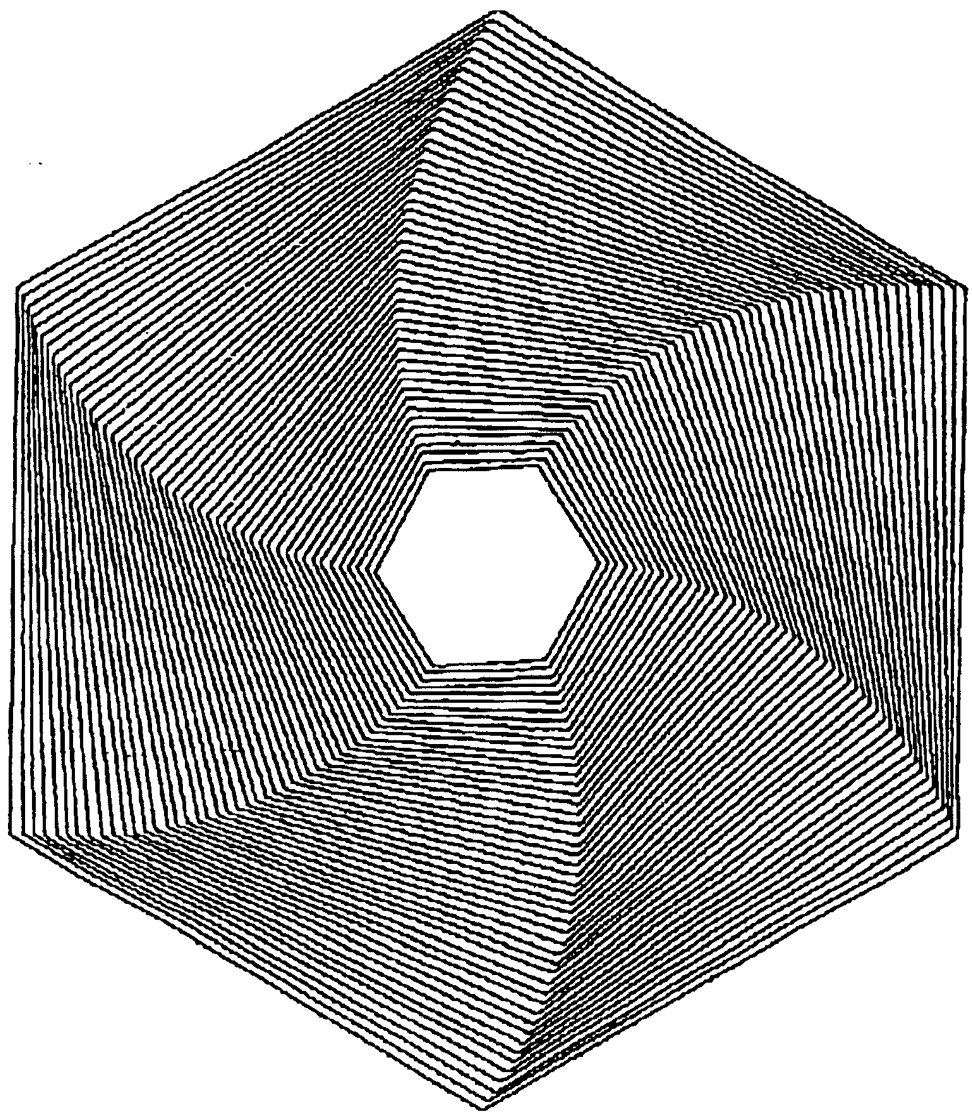


FIG. 6

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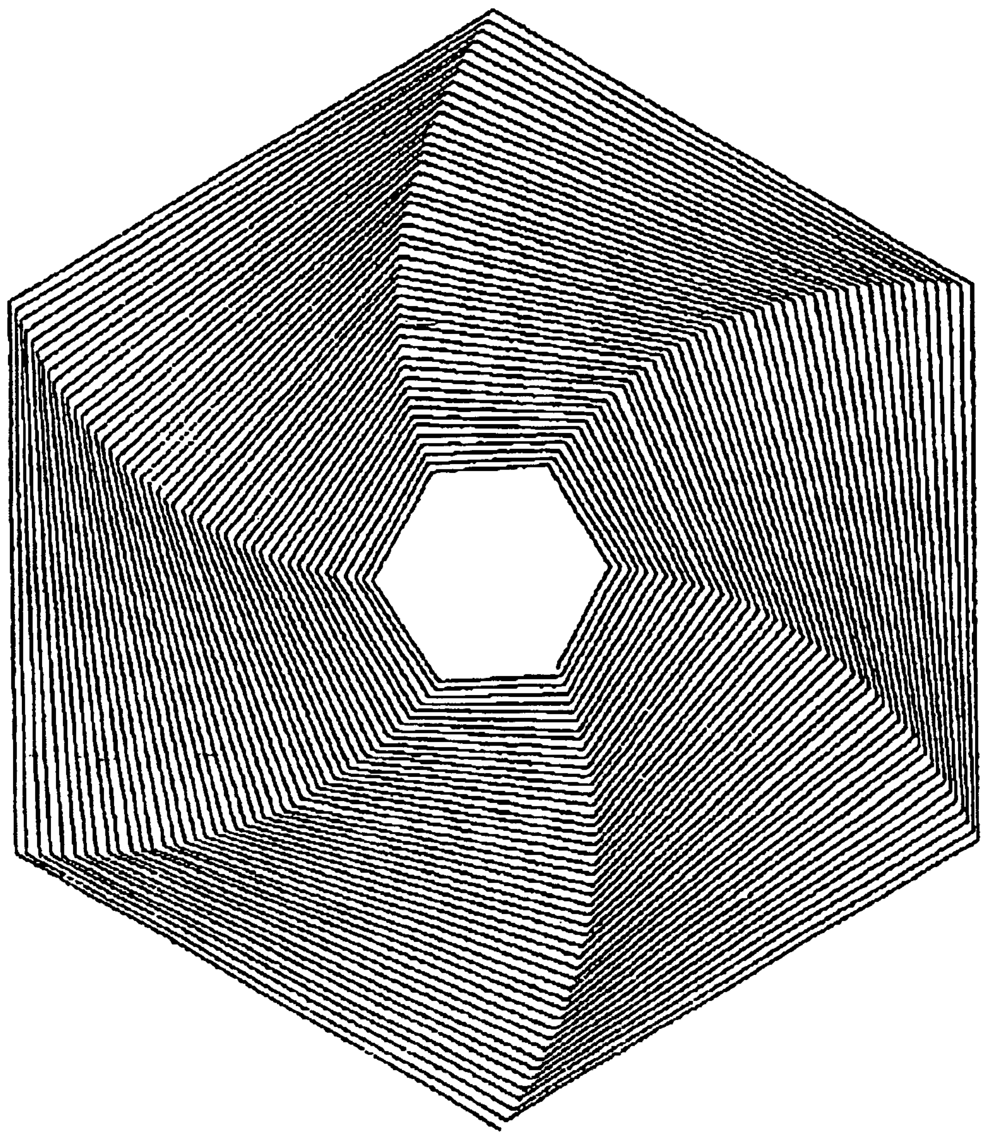

FIG. 7

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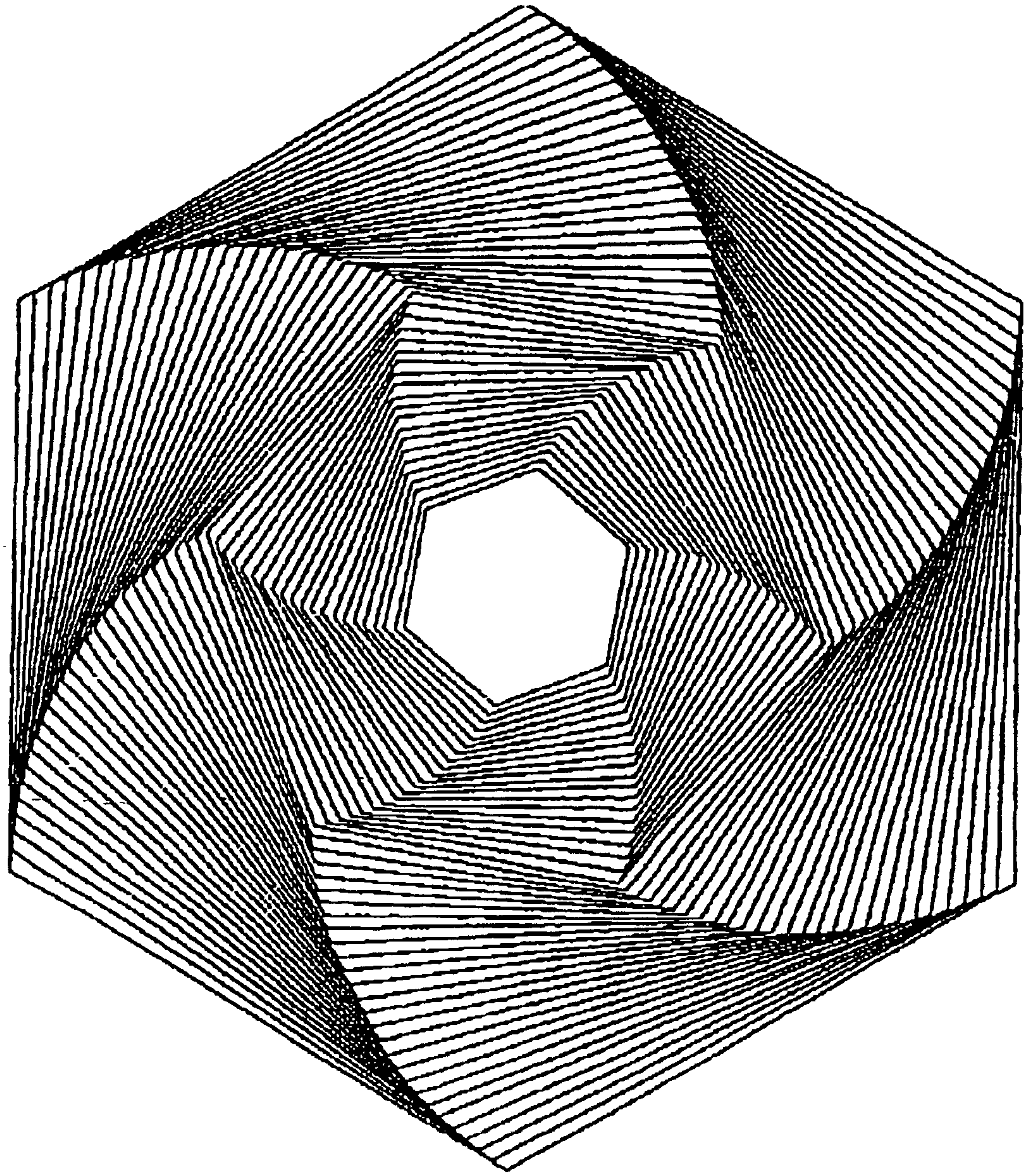

FIG. 8

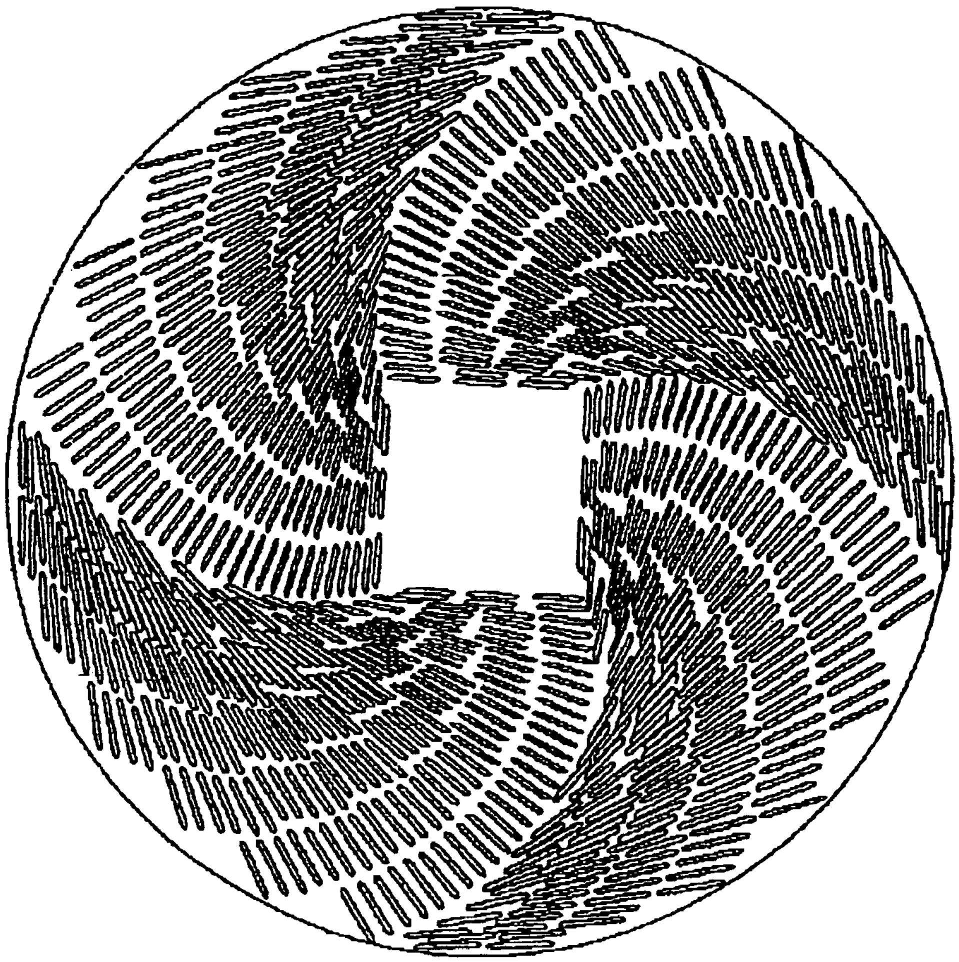

FIG. 9

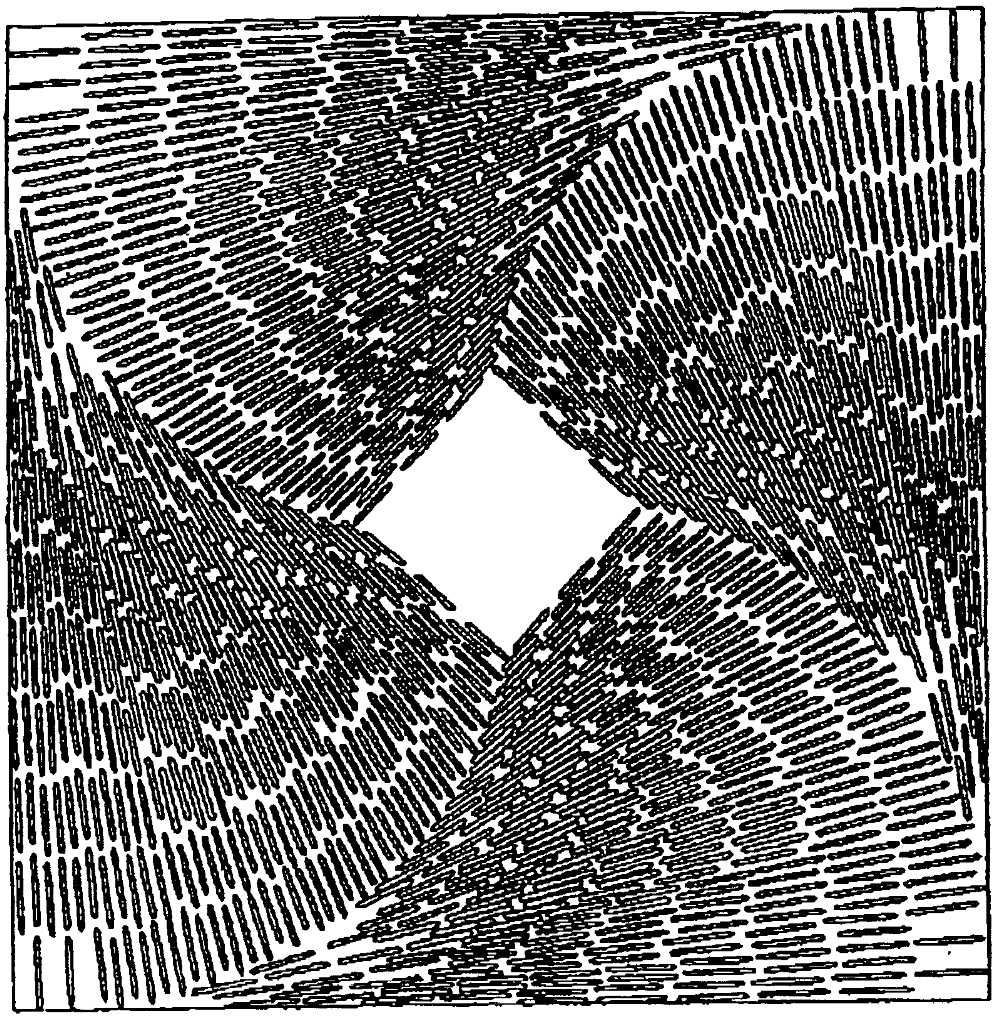

FIG. 10

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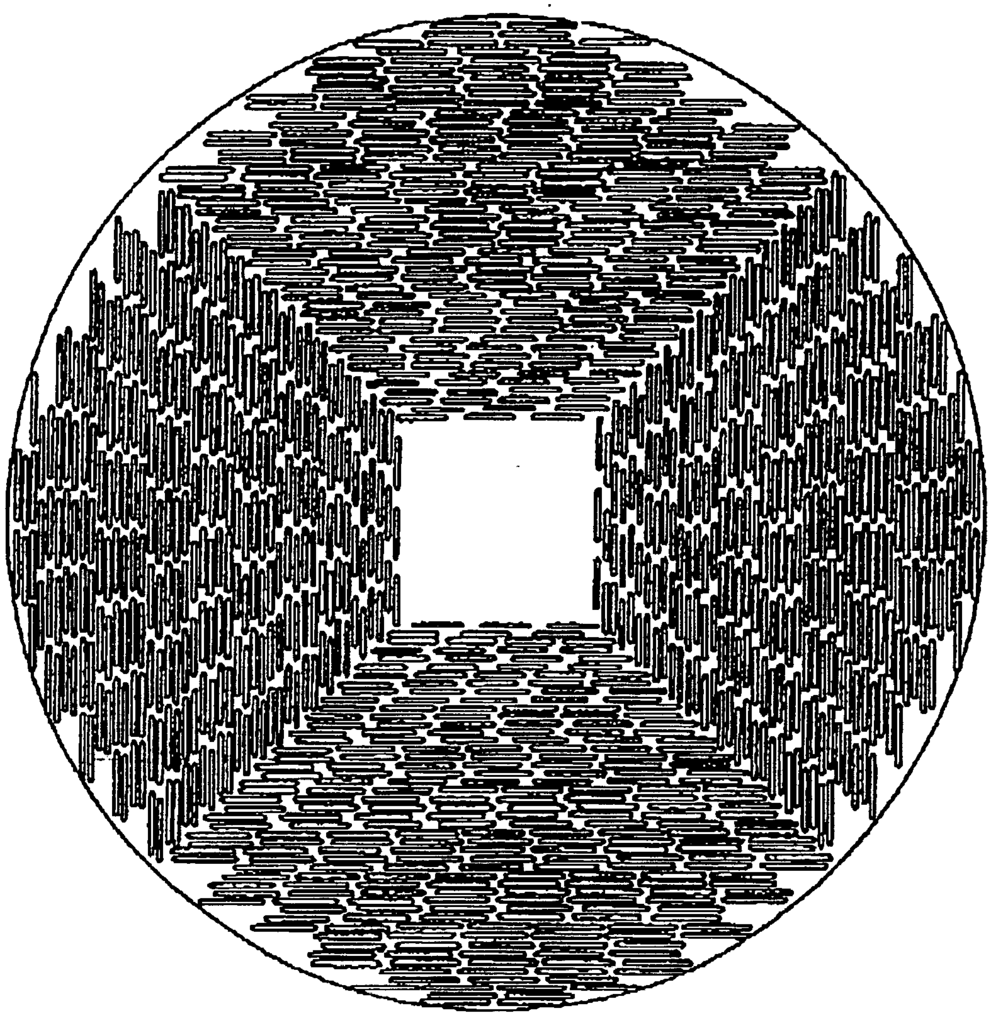

FIG. 11

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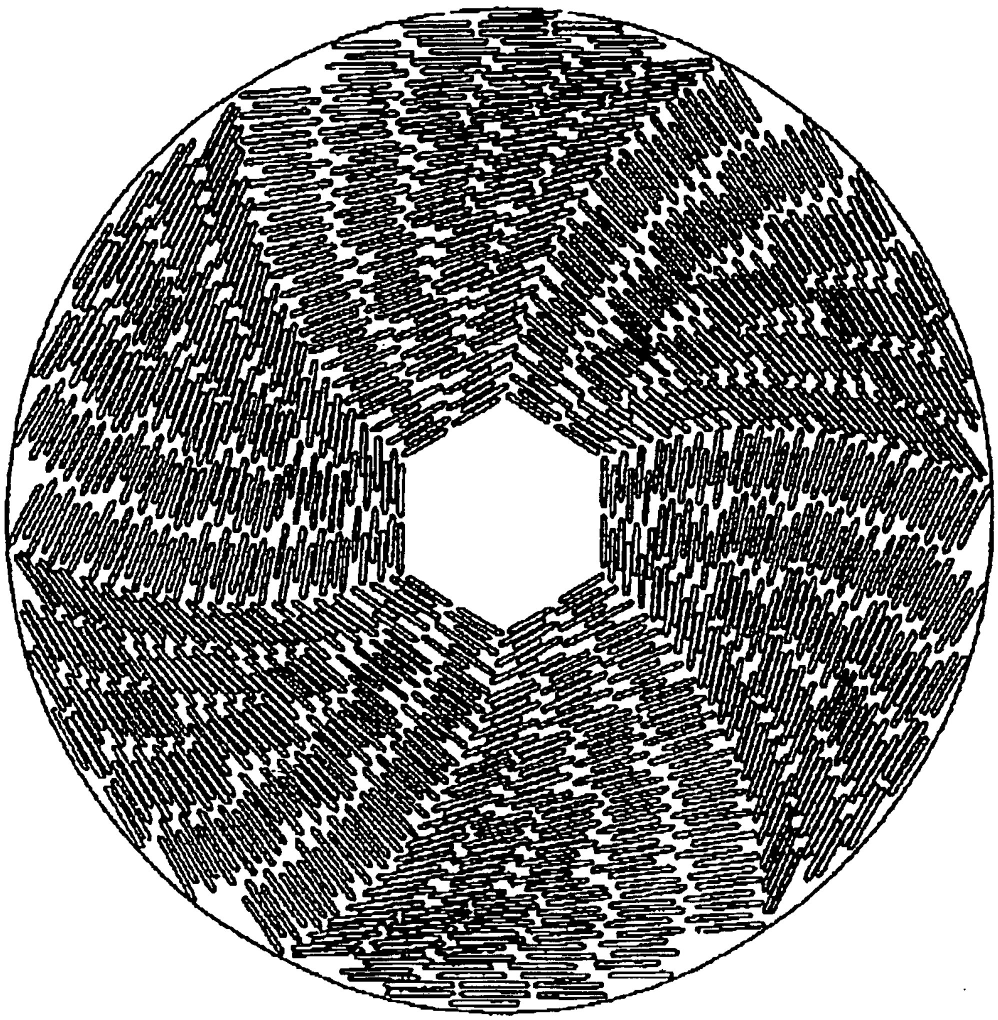

FIG. 12

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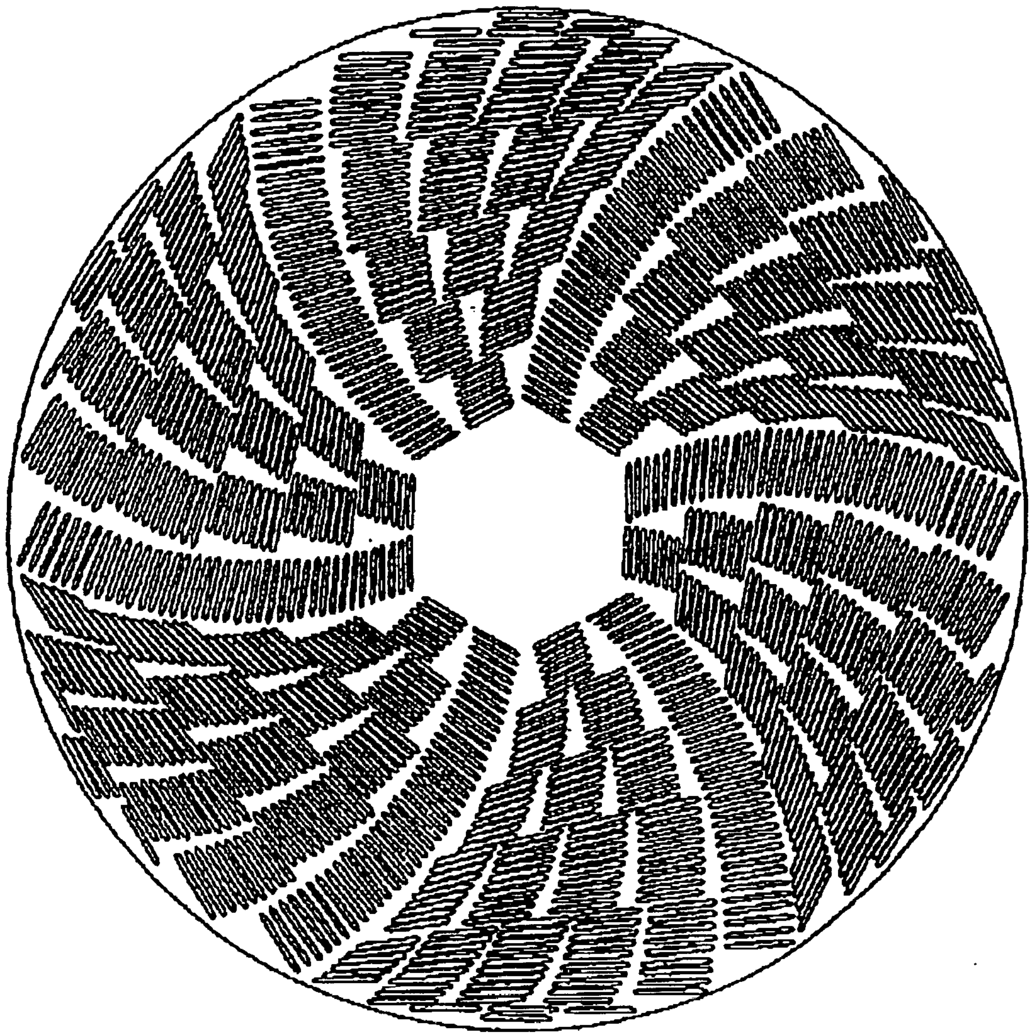

FIG. 13

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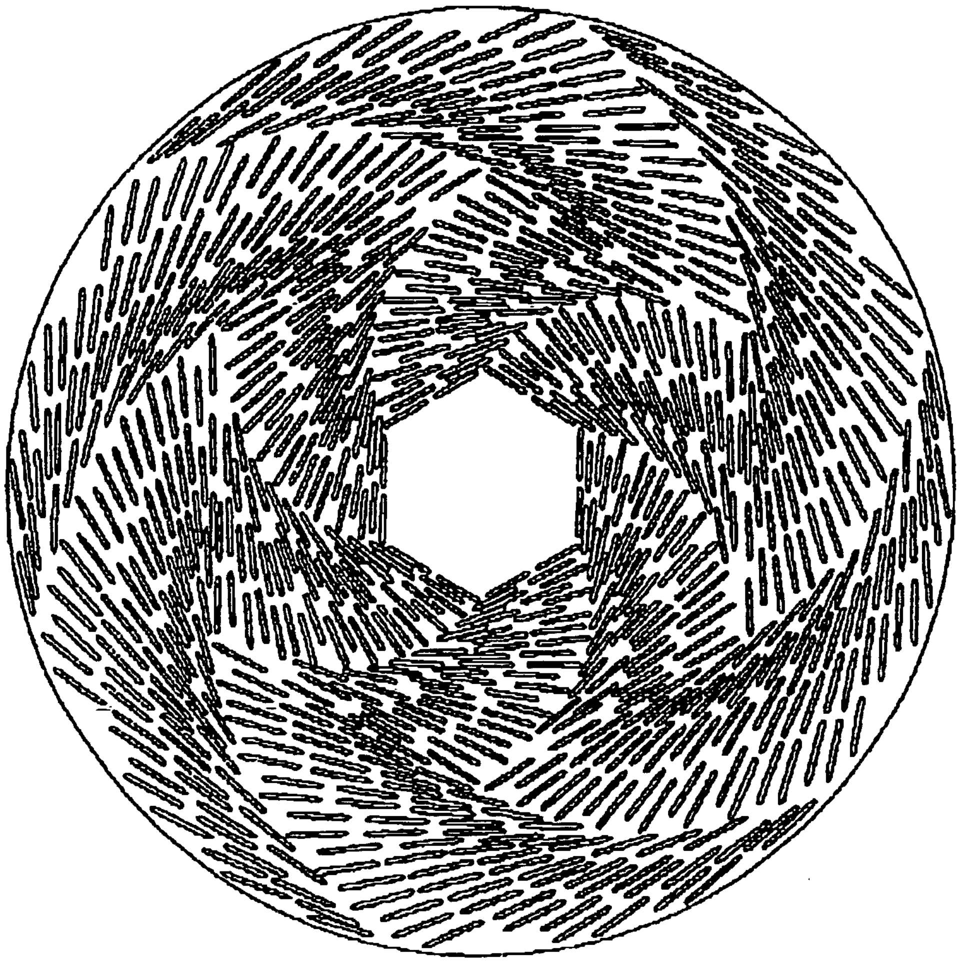

FIG. 14

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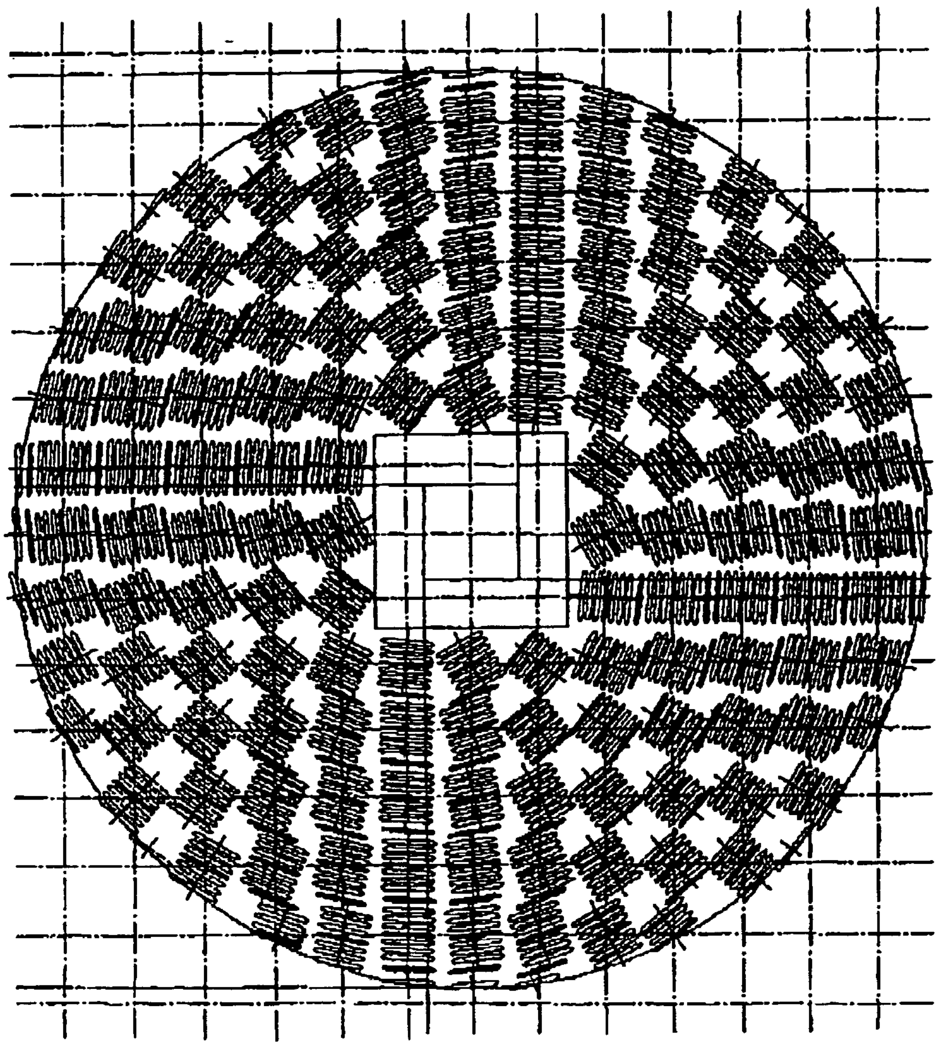

FIG. 15

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PLASMA TREATMENT SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to a plasma treatment system suitable for a treatment, such as CVD, etching, sputtering or ashing.

2. Description of the Prior Art

In recent years, with the densification and high definition of semiconductor products, a plasma treatment system for performing a treatment, such as thin-film deposition, etching or ashing, is used in a process for producing semiconductor products.

Conventionally, as plasma treatment systems of this type, there are known a system wherein a microwave inlet is provided in a plasma producing chamber having a magnetic field forming means to form an electron cyclotron resonance cavity to draw ions from the plasma producing chamber to irradiate a semiconductor wafer with ion beams in a reaction chamber (Japanese Patent Publication No. 58-13626), and a system for introducing microwaves into a cavity resonator from one end thereof through a waveguide to radiate microwaves into a plasma producing chamber from a slot provided at the other end of the resonator (Japanese Patent Laid-Open No. 63-293825).

However, since the system disclosed in Japanese Patent Publication No. 58-13626 has the plasma producing chamber and the reaction chamber, there is a problem in that the size of the whole system is great. In addition, since the system disclosed in Japanese Patent Laid-Open No. 63-293825 has the cavity resonator and the plasma producing chamber, there is the same problem.

On the other hand, in a plasma treatment system wherein a circular microwave radiating plate member (a flat antenna member) having spirally or concentrically arranged slots is mounted on the tip of a coaxial guide to be arranged in a vacuum vessel (a treatment vessel) having a discharge space and wherein a sample, such as a semiconductor wafer, arranged in the vacuum vessel so as to face the microwave radiating plate member is irradiated with microwaves (Japanese Patent Laid-open No. 1-184923 and 8-111297), it is possible to miniaturize the whole system since the vacuum vessel itself has a cavity resonator structure.

However, in the above described system disclosed in Japanese Patent No. 8-111297, there is a problem in that it is not possible to input an electric power higher than some extent even if a great electric power is intended to be input in order to obtain a high density plasma.

Therefore, the inventors have proposed a plasma treatment system for solving this problem in Japanese Patent Application No. 8-153357 (Japanese Patent Laid-Open No. 9-181052). In this plasma treatment system, the length of each of slots formed in a flat antenna member and the space between adjacent two of the slots are different from those of the above described system disclosed in Japanese Patent Laid-Open No. 8-111297, so that an electric field exponentially attenuating as leaving the surface of the flat antenna member can be formed in a treatment space in a treatment vessel. The radial space between adjacent two of the slots of the flat antenna member is set to be preferably in the range of from 5% to 50% of the coaxial guide wavelength of microwaves (substantially the same value as the coaxial guide wavelength in the case of the plasma treatment system disclosed in Japanese Patent Laid-Open No. 8-111297), and the length of each of the slots is set to be preferably in the range of (½)±30% of the coaxial guide wavelength (in the range of from about ½ of the coaxial guide wavelength to about ½ of a free space wavelength in the case of the plasma treatment system disclosed in Japanese Patent Laid-Open No. 8-111297).

According to the plasma treatment system with this construction, since an electric power for producing plasma is inputted via an electrostatic field, not via an electromagnetic field, there is no upper limit to the input electric power, so that it is possible to efficiently the electric power.

However, it was revealed that, in this plasma treatment system, there is a problem in that the intensity of the electric field in the treatment space facing the central portion of the flat antenna member increases. The inventors consider that the reason for this is as follows. The microwaves supplied from the inner conductor of the coaxial waveguide to the center of the flat antenna member propagate in radial directions while being radiated into the treatment space via the slots. Since the space between adjacent two of the slots is set to be the above described value in this plasma treatment system, a very small amount of microwaves are radiated radially outside via the slots. Therefore, most of the microwaves reflect on a radial edge (the inner wall surface of a radial waveguide box of a conductive material) to be returned. Then, the returned microwaves are radiated radially inside via the slots. Since the normal line of each of the slots formed-in the flat antenna member passes through the center of the flat antenna member, the microwaves radiated from the slots concentrate on the treatment space facing the central portion of the flat antenna member, and the intensity of the electric field herein increases.

In addition, in the above described plasma treatment system proposed in Japanese Patent Laid-Open No. 9-181052, it was revealed that the density of plasma directly beneath a quartz glass disposed on the bottom surface of the flat antenna member, i.e., the density of plasma in a plasma forming region, is ununiform. It is considered that the reason for this is that, if the slot pattern formed in the flat antenna member is axisymmetric, the axisymmetric coaxial waveguide resonates with the axisymmetric flat antenna member in an inherent mode. Furthermore, the expression "axisymmetric" means that, like a concentric circle, the shape of the coaxial waveguide or flat antenna member does not change even if it is rotated about the center of the flat antenna member by an optional angle.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to eliminate the aforementioned problems and to provide a plasma treatment system capable of relieving the increase of the electric field in a treatment space facing the central portion of the flat antenna member by devising the length of each of slots formed in a flat antenna member, the space between adjacent two of the slots and the arrangement thereof.

It is another object of the present invention to provide a plasma treatment system capable of relieving the ununiformity of the density of plasma in a plasma forming region by devising the length of slots formed in a flat antenna member, the space between adjacent two of the slots and the arrangement thereof.

In order to accomplish the aforementioned and other objects, a plasma treatment system comprises: an airtight treatment vessel housing therein a mounting table for mounting thereon an object to be treated; microwave generating device for generating a microwave; microwave intro-

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ducing device for introducing the microwave into the treatment-vessel; and a flat antenna member which is connected to the microwave introducing device and which faces the mounting table, the flat antenna member having a plurality of slots in a region other than a central portion of the flat antenna member, the slots being arranged so as not to be axisymmetric with respect to an axis passing through the center of the flat antenna member, a space between adjacent two of the slots being shorter than a wavelength of the microwave in the microwave introducing device, and each of the slots having a length shorter than half of the wavelength.

According to the plasma treatment system with this construction, while microwaves supplied from the microwave introducing device to the flat antenna member propagate in radial directions of the flat antenna member, a small amount of microwaves are radiated radially outside via the slots. Most of microwaves reflect on the radial edge to be returned. During this process, the microwaves are radiated radially inside via the slots. Although the microwaves radiated while propagating in the radial directions are synthesized with the microwaves radiated while reflecting to be returned, the electric field of the radiated microwaves is prevented from increasing in the treatment space facing the central portion of the flat antenna member since the slots are arranged so as not to be axisymmetric. The expression "not to be axisymmetric" means that, when the flat antenna member is rotated about an axis passing through the center of the flat antenna member by an optional angle, the flat antenna member before the rotation is not coincident with the flat antenna member after the rotation. The axis passing through the center of the flat antenna member means a line which passes through the center of the flat antenna member and which is perpendicular to the surface of the flat antenna member.

In addition, since the microwaves supplied from the microwave introducing device to the center of the flat antenna member propagate in directions offset from the radial directions of the flat antenna member when being radiated into the treatment space via the slots, it is possible to avoid the resonance of the waveguide **52** with the flat antenna member **44**. By these two functions, it is possible to produce uniform plasma onto the mounting table.

Moreover, since the microwaves radiated in radial directions have an electric field component perpendicular to the surface of the antenna member, molecules of a plasma gas supplied into the treatment vessel can be efficiently heated by the electric field component. As a result, the efficiency for absorbing the electric power is improved, so that it is possible to efficiently produce plasma.

According to the present invention, since the slots are arranged in the region other than the central portion of the flat antenna so as not to be axisymmetric, it is possible to relieve the increase of the electric field of microwaves, which are radiated from the flat antenna, in the treatment vessel facing the central portion of the flat antenna member, and it is possible to relieve the ununiformity of the density of plasma in the plasma forming region. Thus, it is possible to produce uniform plasma onto the mounting table. In addition, it is possible to efficiently produce plasma by the electric field component of microwaves radiated substantially in radial directions from the flat antenna member.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be understood more fully from the detailed description given herebelow and from the accompanying drawings of the preferred embodiments of the invention. However, the drawings are not intended to imply limitation of the invention to a specific embodiment, but are for explanation and understanding only.

In the drawings:

FIG. **1** is a sectional view of a preferred embodiment of a plasma treatment system according to the present invention;

FIG. **2** is a schematic diagram for explaining slots in an antenna member of FIG. **1**;

FIG. **3** is a schematic diagram for explaining an example of a procedure for forming a slot pattern;

FIG. **4** is a schematic diagram showing an example of a slot pattern formed by the procedure of FIG. **3**;

FIG. **5** is a schematic diagram for explaining a rule for forming another slot pattern;

FIG. **6** is a schematic diagram for explaining a rule for forming another slot pattern;

FIG. **7** is a schematic diagram for explaining a rule for forming a further slot pattern;

FIG. **8** is a schematic diagram for explaining a rule for forming a still further slot pattern;

FIG. **9** is schematic diagram showing an example of a slot pattern corresponding to FIG. **5**;

FIG. **10** is a schematic diagram showing another example of a slot pattern corresponding to FIG. **5**;

FIG. **11** is a schematic diagram showing a further example of a slot pattern corresponding to FIG. **5**;

FIG. **12** is a schematic diagram showing a still further example of a slot pattern corresponding to FIG. **5**;

FIG. **13** is a schematic diagram showing an example of a slot pattern corresponding to FIG. **7**;

FIG. **14** is a schematic diagram showing an example of a slot pattern corresponding to FIG. **8**; and

FIG. **15** is a schematic diagram showing another example of a slot pattern.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the accompanying drawings, a preferred embodiment of a plasma treatment system according to the present invention will be described in detail below. FIG. **1** is a sectional view of a preferred embodiment of a plasma treatment system according to the present invention.

In this preferred embodiment, a plasma treatment system applied to a plasma etching system will be described. As shown in FIG. **1**, a plasma etching system **2** has a cylindrical treatment vessel **4** having a side wall and a bottom which are made of a conductive material, such as aluminum. The treatment vessel **4** defines therein a closed treatment space SP.

The treatment vessel **4** houses therein a mounting table **6** for mounting thereon a semiconductor wafer **W** serving as an object to be treated. The mounting table **6** is made of aluminum treated with alumite, and has a substantially cylindrical shape having a convex flat central portion. The bottom of the mounting plate **6** is supported on a cylindrical supporting table **8** of aluminum. The supporting table **8** is mounted on the bottom of the treatment vessel **4** via an insulating material **10**.

On the top surface of the mounting table **6**, an electrostatic chuck and clamp mechanism (not shown) for holding the wafer are mounted. The mounting table **6** is connected to a

matching pump **14** and a biasing high-frequency power supply **16** of, e.g., 13.56 MHz, via a feeder **12**. The supporting table **8** for supporting thereon the mounting table **6** is provided with a cooling jacket **18** for allowing cooling water to pass therethrough for cooling the wafer during a plasma treatment. The side wall of the treatment vessel **4** is provided with a plasma gas supply nozzle **20** of a quartz pipe for supplying a plasma gas, e.g., argon gas, into the vessel, and a treatment gas supply nozzle **22** of, e.g., a quartz pipe, for introducing a treatment gas, e.g., an etching gas. These nozzles **20**, **22** are connected to a plasma gas source **36** and a treatment gas source **38** by means of gas supply paths **24**, **26** via mass flow controllers **28**, **30** and shut-off valves **32**, **34**, respectively. The etching gas serving as the treatment gas may be CF_3, CHF_3 or CF_4 gas. The outer periphery of the side wall of the treatment vessel **4** is provided with a gate valve **40** which is open and closed when introducing/discharging the wafer into/from the treatment vessel **4**.

Moreover, an outlet **42** connected to a vacuum pump (not shown) is formed in the bottom of the treatment vessel **4** to evacuate the treatment vessel **4** to a predetermined pressure if necessary.

On the other hand, the top of the treatment vessel **4** is provided with a flat antenna member **44** for forming an electrostatic field. The flat antenna member **44** is formed as the bottom of a radial waveguide box **46** of a low cylindrical hollow vessel. The radial waveguide box **46** is arranged so as to face the mounting table **6**. The radial waveguide box **46** is substantially disk-shaped and made of a conductive material, e.g., aluminum. Over the whole bottom surface of the antenna member **44**, a quartz glass plate **48** having a thickness of, e.g., 2 mm, is airtightly provided as a protective plate for protecting the antenna member **44** from plasma while airtightly holding the interior of the radial waveguide box **46**. In place of the quarts glass plate **48**, a ceramic thin plate or the like may be used as the protective plate.

One end of the outer tube **52A** of a waveguide **52** is connected to the central portion of the top surface of the radial waveguide box **46**, and the other end thereof is connected to a microwave generator **50** of, e.g., 2.45 GHz. The inner cable **52B** of the waveguide **52** is connected to or slightly spaced from the central portion of the disk-shaped antenna member **44**. In the figure, the inner cable **52B** is connected to the central portion of the disk-shaped antenna member **44**. While the coaxial waveguide has been used as an example of a waveguide, a circular sectional or rectangular waveguide may be used.

At the connecting portion of the waveguide **52** to the radial waveguide box **46**, a sealing material **58** of, e.g., a ceramic seal, is airtightly provided in the waveguide **52** by brazing or the like to hold the vacuum in the radial waveguide box **46**.

On the other hand, the radial waveguide box **46** houses therein a dielectric **62** having a predetermined dielectric constant for decreasing the wavelength of microwaves, which are supplied to the flat antenna member, to be a shorter guide wavelength. The dielectric **62** may be a material having a small dielectric loss, such as Al_2O_3, Al or SiN. The distance D between the bottom surface of the flat antenna member **44** and the top mounting surface of the mounting table **6** is set to be in the range of, e.g., from about 5 cm to about 10 cm, so that the treatment space SP is divided into a plasma forming region **SP10** and a process region **SP20**, in which treatment is actually performed with active species of plasma diffusing from the plasma forming region **SP10**.

The flat antenna member **44** comprises a disk of a conductive material, e.g., a copper disk, having, e.g., a diameter of 50 cm and a thickness of about 0.1 to 2.0 mm, preferably 0.3 to 1.0 mm.

Referring to FIG. **2**, the characteristics of slots formed in the flat antenna member **44** will be described below. In this figure, the center **44A** of the disk-shaped antenna member **44** and three slots **60A**, **60B** and **60C** are shown.

The length L1 of each slot is set to meet the condition of $0<L1<\lambda g/2$ wherein λg is a waveguide wavelength of microwaves. The lengths of the respective slots are not required to be equal to each other as long as the lengths meet the above described condition. For example, the peripheral portion thereof may be longer than another portion. The length L1 of each slot is set to be preferably in the range of $\lambda g/10 \leqq L1 \leqq \lambda g/2$.

A slot space L2 is set to meet the condition of $0<L2<\lambda g$. The slot space is defined as the difference between distances between the center **44A** of the disk-shaped antenna member **44** and the centers of two slots, one of which is a certain slot selected as a reference slot and the other of which is a slot nearest to the reference slot. For example, in the case of FIG. **2**, the space between the slots **60B** and **60C** is the difference between a distance L3 between the center **60BO** of the slot **60B** and the center **44A** of the disk-shaped antenna member **44** and a distance L4 between the center **60CO** of the slot **60C** and the center **44A** of the disk-shaped antenna member **44**. Similar to the length of the slot, the slot spaces are not required to be equal to each other. For example, the peripheral portion may be shorter than other portions. The slot space L2 is set to be preferably in the range of $\lambda g/33 \leqq L2 \leqq \lambda g/2$, and is set to be more preferably in the range of $\lambda g/20 \leqq L2 \leqq \lambda g/4$.

The length of each slot is greater than the width thereof. Both end portions of each slot in longitudinal directions are round. The width of each slot is preferably in the range of from 1 to 4 mm.

Each slot is oriented so that the normal line VL thereof does not pass through the central portion of the disk-shaped antenna member **44**. The normal line of a slot means a straight line perpendicular to a longitudinal direction of the slot at the center thereof. Thus, since each slot is oriented so that the normal line VL thereof does not pass through the central portion of the disk-shaped antenna member **44**, the increase of the electric field in the treatment space facing the central portion of the flat antenna member is relieved even if microwaves reflecting on the inner wall surface of the radial waveguide **46** to be returned pass through the slots to be radiated radially inside. In addition, the fact that each slot is oriented so that the normal line VL thereof does not pass through the central portion of the disk-shaped antenna member **44** means that the slot pattern is not axisymmetric. Therefore, microwaves supplied from the inner conductor **52B** of the waveguide **52** to the center of the flat antenna member **44** propagate in directions offset from the radial directions of the flat antenna member **44** when being radiated into the treatment space via the slots. Thus, it is possible avoid the resonance between microwaves within the radial waveguide box **46** and microwaves radiated through the slot into the closed, treatment space SP so that it is possible to relieve the ununiformity of the density.

Referring to FIG. **3**, an example of a method for forming such a slot pattern will be described below. Such a slot pattern may be formed by the following steps (1-1) through (1-8).

(1-1) Draw an optional straight line A passing through the center O of a flat antenna member ANT.

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(1-2) Take a point B apart from the center O by a distance La (La>0).

(1-3) Draw a straight line C which passes through the point B and which is perpendicular to the straight line A. For example, the straight line C may only a half counterclockwise with respect to the straight line A.

(1-4) Take a point E on the straight line C so as to be apart from the point B by a distance Lb (Lb≧0).

(1-5) Arrange a slot S1 which passes through the point E and which is perpendicular to the straight line C. It is assumed that the length of the slot S1 is SL1 (SL1>0) and that the point E is the center of the slot S1.

(1-6) Sequentially arrange slots Sx in the opposite direction to the point B with respect to the point E so as to be apart from the point E by a predetermined distance SSx (x is an integer from 2 to N). The slots Sx are arranged to the outermost periphery of the flat antenna member ANT. Furthermore, FIG. 3 shows slots S1 through S4.

(1-7) Take a point B' on the straight line A in the opposite direction to the point B with respect to the point O so as to be apart from the point O by a distance La' (La'>O).

(1-8) carry out the above described steps (1-3) through (1-6) to obtain a straight line C', a point E' and slots Sx' (x' is an integer from 1 to N). The values La, La', Lb and Lb' (Lb' is not shown) are adjusted so that Sx' does not interfere with Sx.

(1-9) Rotate the straight line A, e.g., clockwise by a predetermined angle Θ to obtain a straight line A1. In the figure, Θ is about 45°.

(1-10) Carry out the above described steps (1-2) through (1-8) to arrange slots on two straight lines C1 and C1' (not shown) which are perpendicular to the straight line A1 and which are in the opposite directions with respect to the center O.

(1-11) Change the rotation angle Θ to repeat the above described steps (1-9) and (1-10) until there is no blank in the outer peripheral portion of the antenna.

Furthermore, a curve passing through the point B may be prepared in place of the straight line C, and slots may be arranged thereon. While each of the numbers of straight lines C, C' and C1, C1', which are perpendicular to the straight lines A and A1, respectively, has been two, it should not be limited to two, but an optional even or odd number may be selected. When an odd number is selected, slots S1', S2', S3', S4', . . . , may be formed on, e.g., the straight line C perpendicular to the straight line A.

In the above described procedure, the values La and Lb are preferably set so that a blank region (a region wherein no slot is formed) exists in a region having a radius which is not less than the outside dimension of the inner conductor of the waveguide, preferably a region having a radius which is not less than the inner diameter of the outer conductor of the waveguide and which is not greater than the guide wavelength. Because the state of the electromagnetic field of microwaves in that region is different from that in another place, e.g., in a place apart from the center by about one wavelength. In addition, because the orientation of the vector of the electromagnetic field changes to disturb the electromagnetic field in the connecting portion of the waveguide to the flat antenna member, so that it is required to prevent slots from being provided in a region wherein the disturbance of the electromagnetic field does not converge to some extent. Moreover, because it is required to relieve the increase of the electric field of the treatment space facing the central portion of the flat antenna member ANT and to relieve the ununiformity of the density of plasma directly beneath the flat antenna member.

Furthermore, while the slots shown in FIG. 3 have a rectangular shape for convenience, the slots preferably have an elliptic shape as shown in FIG. 2. when the radius of curvature at both end portions is r, the width of each slot is 2r.

FIG. 4 shows an example of a slot pattern completed by the procedure shown in FIG. 3. In this slot pattern, slots are arranged on **48** straight lines. The **48** straight lines are divided into **12** sets of four lines. In this figure, straight lines corresponding to the straight lines A, C, C', A1, C1 and C1' of FIG. 3 are shown by thick lines, to which signs are applied (however, the straight line A1 is rotated clockwise from the straight line A by about 45° in FIG. 3, but by about 30° in FIG. 4). Each set of straight lines intersect at a region, in which no slot is formed. The center of each slot exists on the straight line, and the normal line of each slot is oriented in the same direction as that of the straight line. Furthermore, in this slot pattern, each set of four straight lines may be parallel to each other. In addition, the normal lines of slots on each straight line are not required to be oriented in the same direction. Moreover, the centers of the slots are not required to be arranged on the straight line.

Referring to FIGS. **5** through **8**, slot patterns different from those in FIG. 3 and FIG. 4 will be described below. These slot patterns have the same features as the three features described referring to FIG. 3, i.e., the three features that the length of each slot is smallerthan λg/2, the slot space is smaller than λg, and the blank region is provided in the central portion. However, the normal line of each slot may or may not pass through the central portion of the flat antenna member. These slot patterns are arranged in the following rules (2-1) through (2-9).

Furthermore, for example, the blank region of the central portion is a region facing an end opening facing the flat antenna member **44** of the waveguide **52**, and the region other than the central portion of the flat antenna member **44** is a region outside the blank region.

(2-1) Slots are arranged on the sides of an imaginary polygon on the antenna surface of the flat antenna member. The polygon is preferably any one of a quadrangle to an octagon. FIG. 5 shows an example of a quadrangle, and FIGS. 6 through 8 show examples of hexagons.

(2-2) A common center is arranged outside of a polygon formed in the central portion of the flat antenna member, and a plurality of polygons having gradually increasing sides are formed. The space between substantially parallel two sides is set to be 50% or less of the guide wavelength λg, preferably about 30% through 2% thereof.

(2-3) The above described space between the two sides is variable on a plane. For example, the central portion is 10% of λg, the peripheral portion is about 3% thereof, and the portion therebetween is linearly interpolated.

(2-4) The polygons are preferably gradually rotated about the center as approaching the outside from the central portion.

The rotation angle is preferably about $\{360/2N\}°$ to $\{360/N\}°$ wherein N is the number of sides of a polygon. Therefore, assuming that the number of polygons formed on a plane is M, the difference between the rotation angles of adjacent polygons is preferably $\{360/2N \cdot M\}°$ to $\{360/N \cdot M\}°$.

In FIG. 5, polygons are rotated clockwise every 1°. In FIG. 6, polygons are rotated clockwise every 0.7°. Furthermore, in a region where the distance between the sides of adjacent polygons decreases, slots are suitably thinned out.

(2-5) The rotation of the polygons should not be limited to a simple rotation in one direction, but it may be combined

with a reverse rotation. For example, when 40 hexagons are formed in a plane, the second to twentieth hexagons from the center are rotated clockwise every 3°, the twenty-first hexagon is rotated counterclockwise every 1.5°, and the twenty-second to fortieth hexagons are rotated counterclockwise every 3°.

In the pattern shown in FIG. 8, 48 hexagons are formed in a plane, the second to twenty-first hexagons from the center are rotated clockwise every 1.5°, and the twenty-second to forty-eighth hexagons from the center are rotated counterclockwise every 1.5°.

(2-6) The respective sides of polygons should not be limited to closed sides, but one side of a polygon may be connected to the vertex of the next outside polygon to continuously form sides. FIG. 7 is an example of a hexagon. Alternatively, a polygon having closed sides may be mixed with a polygon having unclosed sides in a plane.

(2-7) The shape of a plane, in which slots are formed to form a flat antenna member, is a circle or polygon. For example, in accordance with the shape of an object to be treated, the shape of the plane is set to be a circle when the object is a circular wafer, and a quadrangle when the object is a square LCD.

(2-8) The lengths of the slots may be fixed or variable in a plane. For example, the lengths of the slots may increases as approaching the peripheral portion from the central portion. Thus, it is possible to avoid the decrease of the density of plasma produced in a treatment space facing the peripheral portion.

(2-9) As described referring to FIG. 2, each slot preferably has an elliptic shape, and both end portions thereof in longitudinal directions are preferably round. The width of each slot is preferably in the range of from 1 to 4 mm. The length of each slot is preferably in the range of from 1/10 to below ½ of λg.

FIGS. 9 through 13 show examples of slot patterns formed in accordance with the above described rules (2-1) through (2-9).

The slot pattern of FIG. 9 corresponds to that of FIG. 5. This pattern is formed on a circular plane. In this pattern, the sides of each quadrangle are rotated clockwise every 1° as approaching the outside.

The slot pattern of FIG. 10 also corresponds to that of FIG. 5. This pattern is formed on a quadrangular plane. In this pattern, the sides of each quadrangle are rotated clockwise every 1° as approaching the outside. Also in this pattern, slots formed on adjacent sides in lateral directions are alternately offset in longitudinal directions.

The slot pattern of FIG. 11 basically corresponds to that of FIG. 5. However, in this pattern, the sides of each quadrangle are not rotated.

The slot pattern of FIG. 12 corresponds to that of FIG. 6. This pattern is formed on a circular plane. In this pattern, the sides of each hexagon are rotated clockwise every 0.7° as approaching the outside. Also in this pattern, slots formed on adjacent sides in lateral directions are alternately offset in longitudinal directions.

The slot pattern of FIG. 13 corresponds to that of FIG. 7. This pattern is formed on a circular plane. In this pattern, the sides of each hexagon are rotated clockwise every 0.7' as approaching the outside.

The slot pattern of FIG. 14 corresponds to that of FIG. 8. This pattern is formed on a circular plane. In this pattern, the sides of the second to twenty-first hexagons are rotated clockwise every 3°, and the sides of the twenty-second to outermost hexagons are rotated counterclockwise every 3°.

FIG. 15 shows a slot pattern which is different from the slot pattern based on the above described steps (1-1) through (1-8) and from the slot pattern based on the above described rules (2-1) through (2-9). This slot pattern also has four features that the length of each slot is shorter than $\lambda g/2$, the slot space is less than λg, the normal line of each slot does not pass through the central portion of the flat antenna member, and the blank region is provided in the central portion.

This slot pattern is formed by the following procedure. First, an imaginary matrix pattern or check pattern is formed on a plane of a flat antenna member. That is, a plurality of parallel straight lines-are-drawn in longitudinal and lateral directions. Then, a slot is arranged on each of the intersections of the straight lines perpendicular to each other. The slot located at each of the intersections is called a center slot. The orientation of the center slot is set so that the respective normal lines do not pass through the central portion of the flat antenna member. Then, some slots are arranged on both sides of each center slot (only inside in the outer peripheral portion). The slots arranged on both sides of each center slot are oriented in the same direction as that of each center slot. The center slot and the slots on both sides thereof (only inside in the outer peripheral portion) constitute one group of slots. Furthermore, the center slot may be arranged at the center of each quadrangle formed by straight lines perpendicular to each other, not at the intersection of the straight lines, and some slots may be arranged on both sides thereof.

With the above described construction, the operation of the plasma treatment system in this preferred embodiment will be described below. First, the semiconductor wafer W is introduced into the treatment vessel 4 via the gate valve 40 by means of a transport arm, and the wafer W is mounted on the mounting top surface of the mounting table 6 by vertically moving a lifter pin (not shown).

Then, a vacuum pump is operated to hold the pressure in the treatment vessel 4 to be a predetermined process pressure, e.g., in the range of from 0.1 to tens mTorr, and the mass flow controller 28 and the shut-off valve 32 are operated to supply argon gas from the plasma gas supply nozzle 20 while controlling the flow thereof. In addition, the mass flow controller 30 and the shut-off valve 34 are operated to supply an etching gas, e.g., CF_4 gas, from the treatment gas supply nozzle 22 while controlling the flow thereof. Simultaneously, microwaves are supplied from the microwave generator 50 to the antenna member 44 via the waveguide 52 to form an electric field in the treatment space SP to produce plasma to carry out an etching treatment.

The microwaves of, e.g., 2.45 GHz, generated by the microwave generator 50 propagate through the coaxial waveguide 52 in a TEM mode to reach the antenna member 44 of the radial waveguide box 46. While the microwaves propagate from the center of the flat antenna member 44, which is connected to the inner cable 52B, radially to the peripheral portion, the microwaves are radiated into the upper portion of the treatment space SP directly beneath the antenna member, specifically into the plasma forming region SP10 substantially in radial directions, via the large number of slots 60 formed in the antenna member 44. In addition, the microwaves which are radiated from the slots 60 and which are reflected on the radial edges of the flat antenna member (the inner wall surface of the radial waveguide box 46) to be returned are also radiated to the plasma forming region SP10 substantially in radial directions. Since substantially radially radiated microwaves have an electric field component perpendicular to the plane of the flat antenna member 44, argon gas excited by the electric field component is activated as plasma to be diffused in the process region SP20 to activate the treatment gas to form active species to treat, e.g., to etch, the wafer W with the active species.

In this preferred embodiment, since the length of each slot, the space between the slots, and the orientation of each slot are set as described above, the microwaves reflected on the radial edges of the flat antenna member to be returned are radiated substantially radially inside via the slots. However, since the arrangement of the slots is not axisymmetric, it is possible to relieve the increase of the electric field in the plasma forming region **SP10** facing the central portion of the flat antenna member. In addition, since the arrangement of the slots is not axisymmetric, the microwaves supplied from the inner conductor **52B** of the waveguide **52** to the center of the flat antenna member **44** propagate in directions offset from the radial directions of the flat antenna member **44** when being radiated into the treatment space through the slots. Thus, it is possible to avoid the resonance between microwaves within the radial waveguide box **46** and microwaves radiated through the slot into the closed, treatment space SP, so that it is possible to relieve the ununiformity of the density of plasma directly beneath the flat antenna member **44**. As a result, it is possible to produce uniform plasma in the process region **SP20**.

While the present invention has been disclosed in terms of the preferred embodiment in order to facilitate better understanding thereof, it should be appreciated that the invention can be embodied in various ways without departing from the principle of the invention. Therefore, the invention should be understood to include all possible embodiments and modification to the shown embodiments which can be embodied without departing from the principle of the invention as set forth in the appended claims.

What is claimed is:

1. A plasma treatment system comprising:

an airtight treatment vessel housing therein a mounting table for mounting thereon an object to be treated;

a microwave generating device for generating a microwave;

a microwave introducing device for introducing said microwave into said treatment vessel; and

a flat antenna member which is connected to said microwave introducing device and which faces said mounting table, said flat antenna member having a plurality of slots in a region other than a central portion of said flat antenna member, said slots being arranged so as not to be axisymmetric with respect to an axis passing through the center of said flat antenna member, a slot space for two of said slots being shorter than a wavelength of said microwave in said microwave introducing device, and each of said slots having a length shorter than half of said wavelength,

wherein said slots are arranged so that a normal line of each of said slots does not pass through said central portion of said flat antenna member and said slots are arranged on and perpendicular to a plurality of straight lines which are imaginatively formed on a plane of said flat antenna member and which do not pass through said central portion of said flat antenna member.

2. A plasma treatment system as set forth in claim **1**, wherein said microwave introducing device is a coaxial waveguide.

3. A plasma treatment system as set forth in claim **2**, wherein said microwave introducing device has an end opening for allowing said microwave to be radiated toward said flat antenna member, and said region other than the central portion of said flat antenna member is a region outside a region facing said end opening.

4. A plasma treatment system as set forth in claim **1**, wherein said slots are arranged on said straight lines so that the orientation of said normal line of each of said slots is the same as those of said straight lines.

5. A plasma treatment system as set forth in claim **1**, wherein said plurality of slots have different lengths.

6. A plasma treatment system comprising:

an airtight treatment vessel housing therein a mounting table for mounting thereon an object to be treated;

a microwave generating device for generating a microwave;

a microwave introducing device for introducing said microwave into said treatment vessel; and

a flat antenna member which is connected to said microwave introducing device and which faces said mounting table, said flat antenna member having a plurality of slots in a region other than a central portion of said flat antenna member, said slots being arranged so as not to be axisymmetric with respect to an axis passing through the center of said flat antenna member, a slot space for two of said slots being shorter than a wavelength of said microwave in said microwave introducing device, and each of said slots having a length shorter than half of said wavelength,

wherein said slots are arranged so that a normal line of each of said slots does not pass through said central portion of said flat antenna member and said plurality of slots comprise a group of slots arranged in the form of a matrix on a plane of said flat antenna member.

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